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THE PHILIPPINE

JOURNAL OF SCIENCE

A. CHEMICAL AND GEOLOGICAL SCIENCES
AND THE INDUSTRIES

VOL. X MAY, 1915 NO. 3

NOTES ON A GEOLOGIC RECONNAISSANCE OF MOUNTAIN PROVINCE, LUZON, P. I.[1]

By WARREN D. SMITH
(From the Division of Mines, Bureau of Science, Manila, P. I.)

FIVE PLATES AND 5 TEXT FIGURES

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SUMMARY.

INTRODUCTION

The following notes are the result of a geologic reconnaissance made by me during March and April, 1914, in the subprovinces of Bontoc and Kalinga with side excursions of less importance into Lepanto and Ifugao.

The rugged nature of the country, the lack of any trained assistants, and the semiwild character of the people combined to prevent the execution of any detailed or accurate work at this time. Primary triangulation is just now being carried out for the first

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[1] Received for publication November 27, 1914.

time, so accurate base maps are wholly lacking. The object of this trip was to traverse as much territory as possible and note the more obvious things of interest first; therefore the following pages will necessarily give fragmentary discussions of the geology of this large area.

FIELD ITINERARY

The route traveled was as follows: Tagudin via Cervantes to Bontoc, Bontoc to Barlig, Barlig to the summit of Mount Amuyao, Barlig to Natonin (southern Kalinga), Natonin to Tabuk, Tabuk to Lubuagan, Lubuagan to Bontoc, Bontoc to Mainit, Bontoc to Lubuagan, Lubuagan to Belotoc, Lubuagan to Balinsogao, Lubuagan to Balbalasan, Balbalasan down the Saltan Valley to Patician, thence to Lubuagan. From here back to Bontoc and on to Sagada, Sagada to Fidelisan and Basao, Sagada to Cervantes and thence to Mancayan, Mancayan to Baguio, and from there to Manila (fig. 1).

Acknowledgments for much assistance in an official capacity and many personal courtesies are hereby made particularly to Gov. E. A. Eckman, of Mountain Province; to Lieut. Gov. Walter Hale, of Kalinga; to Capt. W. E. Moore, senior inspector of Constabulary at Bontoc; and to Lieut. J. F. Oliver, Philippine Constabulary, formerly stationed at Lubuagan. Governor Eckman and Captain Moore accompanied me on my trip through eastern Kalinga, while Lieutenant Oliver accompanied me on several short trips in western Kalinga.

PAST WORK

As far as is known from the literature on the subject, von Drasche is the only geologist who has heretofore gone into the interior of north-central Luzon north of the town of Cervantes, and he traveled only a short distance north of Bontoc and did not go any farther east than Bontoc. He has devoted a chapter in his "Fragmente" to this part of his travels.[2]

As this publication is not easily available, a translation of Chapter VII, which was made for me by Mr. A. E. W. King, Bureau of Science, is inserted here.

THE MILITARY DISTRICTS OF LEPANTO AND BONTOC

The watershed between the large rivers Abra and Agno is only a low chain of hills, consisting of three parallel ranges, having a south-southwesterly direction, and consisting of a weathered sanidine-hornblende-trachyte. Without passing through [the village of] Lipatan, one reaches the hamlet of Mancayan at an elevation of approximately 3,500 feet, which gives a bird's-eye view of the broad valley of the Abra. The formation along the ascent is always a friable trachyte. Toward the east lies the lofty Data, covered with thick forests of oak trees; according to C. Semper this mountain is "an extinct volcano fallen to ruin." There is supposed to be a small lake at the summit. Formerly Mancayan was the scene of extended copper mining, which, however, at present has almost entirely ceased. The ores were already known to the Igorots and were worked by them before the coming of the Spaniards. The courtesy of two Spaniards, who were kind enough to clear away the old rubbish heaps [tailings and gangue] made it possible to obtain an idea of the occurrence of the ores; I also went through several of the galleries myself. The copper minerals occur in a quartz lens found in the sanidine-trachyte, which lens as a whole

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[2] Fragmente zu einer Geologie der Insel Luzon. Wien (1878), 36–46.

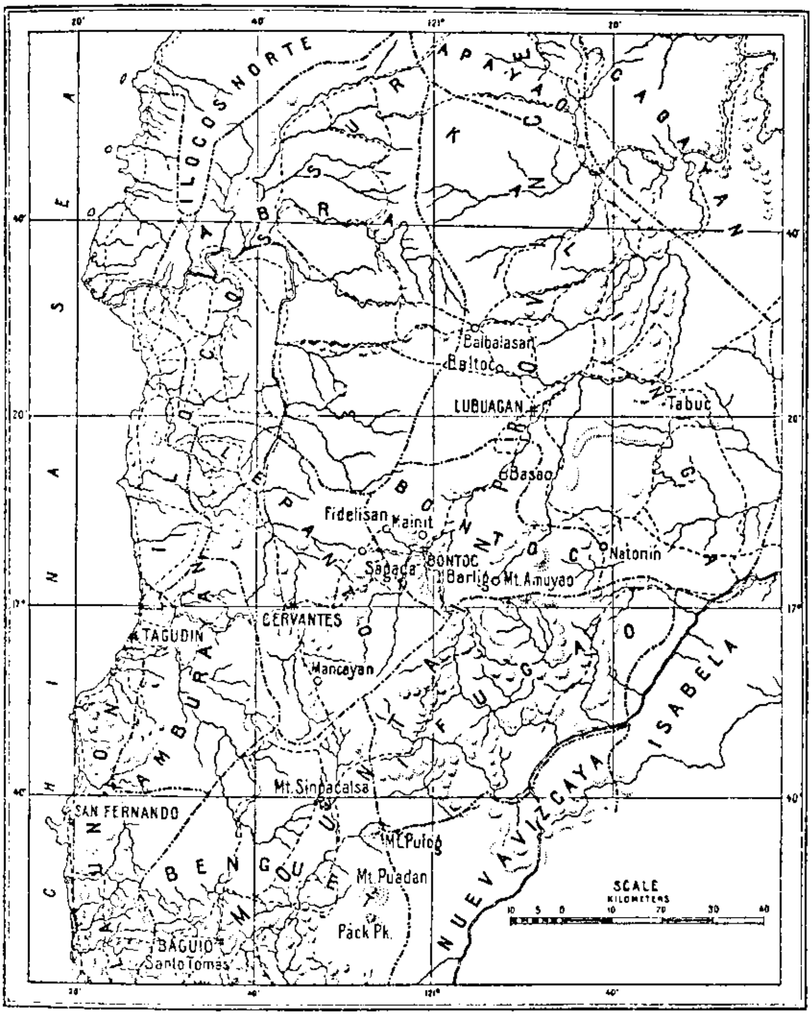

FIG. 1. Outline of northern Luzon, showing region traversed.

appears to have an east and west extension. In this ore body the ore occurs in veins that likewise follow an east-west direction, so that all galleries having a north-south direction expose all the seams. These veins at places are supposed to be 7 meters in width and are uniformly steeply inclined. The distance between these very regular veins, in general, is very little. The ore minerals are principally luzonite, enargite, and covellite, the first-named occurring abundantly in beautiful crystals; besides, I noticed baryte, calcite, copper sulphide, malachite, copper sulphate stalactites, arsenic, and a *saponitartiges* mineral stained blue by copper salts.

Limestone is used in smelting the ores, which is quarried at Mount Malaya, in the cordillera west of Mancayan; judging from the pieces which I saw, it is a coralline limestone. Much gold is said to be panned [washed] south of Mancayan in the mountains of Suyoc and Tubuc, and I was informed also of the occurrence there of hills of gypsum containing crystals of iron-pyrites. According to this information it appears that a part of that extraordinarily serrated mountain chain, which, according to Peñarubio's map continues in the shape of an arch from Suyoc to Pico Tila and then turns directly north, consists of coralline limestone. The northern continuation is, as we shall see, formed almost entirely of this stone.

I continued my journey from Mancayan to Cayan, the capital of the district of Lepanto. One descends the heights, consisting of sanidine-hornblende-trachyte, and very soon reaches again a narrow belt of the Agno beds. Before crossing over to the left bank of Abra River, one encounters large bowlders of an excellent rhyolitic quartz-trachyte. It is noteworthy because of its beautiful flow structure. It is possible to differentiate a quartz-trachyte with a dark gray groundmass and another variety with a red groundmass. Both coalesce in varied *Schlieren*, as Dr. Reyer would say.

In this dense, hard, splintery groundmass there are found closely packed, numberless water-white splinters of quartz. These are never rounded, nor do they show the least trace of regular structure, but are always characterized by their fragmental nature; at times they attain a diameter of 4 millimeters. It is interesting to note that the gray Schlieren only contain nests of pyrite. Thin sections of the rock give no information whatsoever concerning the nature of the groundmass. It is very apparent to the eye that the quartz fragments were not formed out of the groundmass; on the contrary, it is apparent that they were enveloped by the magma which formed the groundmass. I regret that I did not succeed in discovering this interesting trachyte, which certainly has an extraordinarily high silicic acid content, in place, although very large blocks of it are found in the river bed of the Abra. As was indicated on page 36 the copper lodes of Mancayan are found to occur in a quartz lens. There are also found with the quartz-trachyte bowlders a great many fragments of a crystalline quartz, which are stained red in places and marked along fracture planes with iron. It might be appropriate to give an explanation of the origin of this remarkable trachyte.

If a dike of the rhyolite broke through one of the quartz lenses, it is very possible that on its borders there would be formed similar breccialike rocks.

The banks of the Abra are composed of an exceedingly coarse, dolerite breccia; the fragments, somewhat rounded and about the size of a clenched hand, are cemented together by an earthy binding material. These pieces protrude from the matrix in groups showing no regularity whatsoever. The steep left banks of the Abra very soon disclose a complex of rocks which clearly show stratification and which have a steep inclination toward the north; they are the well-known plagioclase-hornblende-chlorite rocks, which, alternating with white feldspathic strata full of pyrite, make up the Agno beds.

We finally left the bed of the Abra and went eastward over steep mountains with numerous chasms and cliffs toward Pilipit, and from there to Cayan. The entire region is composed of friable, yellow tuffs, that are mostly stratified horizontally. Numerous creeks flow across these tuffs, engorging themselves in the soft rock; the wearisome trail runs up and down directly across their courses.

Before reaching Pilipit, one has a splendid view of Abra Valley, which spreads into a wide hilly plain a short distance beyond the point where we had left it. Recently successful experiments have been conducted in planting the coffee shrub on this plain.

Cayan has an elevation of about 4,000 feet upon a small plateau. South of the place is the mountain Data. At the foot of Mount Data there are said to be numerous hot springs; copper ores are likewise found there; perhaps this might indicate a great extension of the quartz lens of Mancayan toward the east.

Mount Data plays a very important part in the orography of Luzon; it is, so to say, the watershed of the three great rivers, the Agno, Abra, and Bontoc.

The sources of the first two rivers have already been described; both flow into the ocean on the west coast. Bontoc River, which has its origin in the eastern part of the Data mountain range, very likely flows into Bangong River; therefore it pertains to the river system of the Rio Grande de Cagayan.

In the vicinity of Cagayan the true Central Cordillera is merely a much dissected plateau; at a point much nearer the coast it continues its north-northeasterly direction; consequently Cagayan really is situated on the watershed between the west coast and the Rio Grande de Cagayan. Coello's map does not take cognizance of this noteworthy fact. On Plate I this cordillera is correctly drawn.

Sabangan, which lies a six-hour walk to the east of Cayan, is one of the most remote toward the east of the rancherias paying Spanish tribute. I made a trip to this place in order to enter from there into Bontoc district that lies to the north. A short distance behind Cayan mighty breccias of doleritic rocks are encountered, then breccias of hornblende-sanidine-trachyte, and farther eastward there appears a breccialike rock bedded in thick layers. The last-named consists of large and small, irregular fragments of limestone and of a badly weathered trachytic rock; there are also disseminated fragments of feldspar and quartzite. This conglomerate alternates with strata of coralline limestone, very similar in every respect to that found in Benguet Province. The strata show an inclination to the southeast of 8°–12°. Farther toward the east there again appear soft, yellowish tuffs, which continue as far as the cuartel at Sabangan. Sabangan lies on an eminence, in the angle formed by Sabangan and Bontoc Rivers.

The large rancheria, viewed from the cuartel, lies deep down on the left bank of Bontoc River. The view in this narrow valley, with its sides that jut forth groovelike and upon which are built in steep terraces the well-kept rice fields of the Igorots, is truly splendid.

The shortest way to Bontoc is from Sabangan, provided one follows down the river; by this route it is easy to make the journey to Bontoc in from five to six hours.

This trail, if it may so be called, is absolutely impassable at high water, and even at low water must be traveled afoot on account of the extraordinarily large bowlders. We had brought along horses for our trip in Bontoc, but we had to send them back to Sabangan after trying in vain for one hour to get the animals over the high bowlders. The banks of the river in the vicinity of Sabangan consist of a red, completely decomposed trachyte-tuff, which has an appearance of stratification due to gradations of color. All along the river are found enormous fragments of a coarsely crystalline rock, which is made up of quartz, orthoclase, much plagioclase, and a dark green mineral (chlorite ?) crystallizing in small flexible laminæ. Just out from Sabangan I entered upon the road for Bontoc through Sagada, which is passable for horses. To reach the road it is necessary to cross over to the left bank of a small river, Sabangan River, traversing the yellow tuff formation for a short distance, beyond which one encounters a beautiful quartz-trachyte, which is of considerable extent. This rock is dense, white, and hard, with a splintery fracture. In the dense groundmass one can distinguish white sanidine, glistening like glass, a gray, opaque feldspar crystallized in little columns, quartz in irregular grains, and little crystals of augite—certainly a rare mineral combination. Under the microscope the groundmass resolves itself into a maze of colorless and brown crystals, the latter perhaps being augite microliths. The gray feldspars stand out of the matrix in a most remarkable manner; they are separated from the rest of the groundmass by a sharp, dark border. Augite is rather scarce, while magnetite is present in beautiful crystals. All the disseminated minerals are strongly corroded by the groundmass and contain numerous inclusions. Fig. 3 on Plate III shows very beautiful feldspars in the turbid groundmass.

In the vicinity of Anquilen the trail proceeds in a northerly direction high up on the west wall of the valley.

In the middle of the carefully cultivated, terraced rice fields, with their artificial irrigation system, along this small tributary of the Rio Bontoc, nestle the hamlets Sagada, Balugan, and Anquilen, one above the other. One again crosses bedded series of trachyte-breccias, intercalated with yellow tuffs, and dipping in a southwesterly direction.

No doubt they constitute the northerly continuation of the bedded complex noted between Cayan and Sabangan. At Sagada extensive coralline limestone cliffs are again encountered. These may be traced south almost to Balugan and toward the north to Tetenan. From a distance these give one the impression of a large cemetery with numerous gravestones.

These coral cliffs likewise show stratification with clearly discernible thick beds, usually with a southerly inclination of 15°-20°; between the strata I found a thin layer of greenish tuff. Weathered trachyte is encountered between Tetenan and Bontoc. The greenstone base of the Agno-bed series may be seen at two places also, but over limited areas only. Passing eastward, one very soon reaches Bontoc River at a point where a tributary with exceedingly steep banks enters at right angles from the left.

After having twice crossed the river, Bontoc, the capital of the military district bearing the same name, is reached. It is situated on the left bank of the river, and on the opposite bank lies the important rancheria of Samuqui.

The direction of Bontoc River on Peñarubia's map is shown erroneously as east-west, whereas in reality it is north-northeast. The present governor of Bontoc, Don Hernandez-Permeasolo, has followed the river for three days, always in a northerly direction; warlike Igorots interfere with exploration, so that the farther course of the river is entirely unknown. In my mind there is no question that it flows into one of the western tributaries of the Rio Grande de Cagayan. Peñarubia also indicates this, although the course east of the cordillera is incorrectly shown.

The extremely amiable governor of Bontoc made it possible for me to make an excursion to the most northerly rancherias accessible, Meynit and Sadanga; he even accompanied us personally with military escort. A short distance from Bontoc we again encountered coralline limestone and breccias of coralline limestone and trachyte, which persist to Guinaan. From here, in the direction toward Meynit from Guinaan, there are beautiful green trachytes, which are very splintery, and show here and there isolated, decomposed crystals of feldspar. Bubbling forth from a flat area covered with mud and precipitated salts at Meynit are numerous boiling hot springs, flowing from the fissured ground and escaping as sizzling hot vapors. The vapors spread a faint odor of hydrogen sulphide; the water tastes brackish. The Igorots obtain salt from the hot vapors in a very peculiar manner. They build low straw huts over the fissured locality and cover the floor of the same with stones. Very soon there is formed over these stones thick white crusts of salt, the greater part of which consists of sodium chloride, which the Igorots sell.

The rancherias Meynit and Guinaan lie on a creek which flows into Bontoc River. In order to go from Meynit to Sacasaca, the cuartel of Sadanga, it is necessary to cross over a large mountain densely overgrown with pine trees. A raging thunderstorm and approaching darkness prevented all observations from this mountain.

The rancheria Sadanga is situated on a tributary of Bontoc River, and the cuartel is built upon a cliff some 500 feet high, made up of a decomposed rock rich in feldspar. A very clear, voluminous spring, having a temperature of 34° R. [42°.5 C.], gushes forth from a fissure in this rock. The taste is extraordinarily brackish, and the water precipitates much iron on the rim of the pool; a weak odor of hydrogen sulphide gas is noticeable. The Igorots believe that this spring possesses great healing power and utilize it in the treatment of various diseases.

On our return from Bontoc toward Cayan we followed the road as far as Sagada and then turned westward to the cuartel of Besao and southward toward Cayan. From Sagada to Cayan are doleritic rocks, with green slaglike augite, red olivine rich in iron, and decomposed feldspars, contained in a brown groundmass. The naked, yellow hills, up and down which one toils before reaching Cayan, consist of an entirely decomposed eruptive rock.

The advanced season of the year compelled me to break off my journey in the mountains here, if I were to visit the south of Luzon, and to return to Vigan via Angaqui, there to await the ship that was to take me to Manila.

Cervantes, situated on the left bank of Abra River, is reached by going downhill over a good road from Cayan. The western face of the plateau of Cayan, toward the river, consists of a beautiful hornblende-andesite, which shows on a grand scale spherical segregations built up in concentric layers or shells. The outer shells are mostly very much decomposed; however, inside one encounters sound cores.

From Cervantes the road follows the left bank of the river; it was formerly called Camarin [camino?] del Rio. The valley is very broad here; to the east are the towering mountains of the cordillera; to the west, extending from north to south, is the costal range, whose profile is very jagged. The creeks that flow from its slopes into the Abra carry much coralline limestone, gravel, and decomposed amygdaloidal rocks. On both sides of the river up to 200 feet above its floor there are thick-bedded gravels, through which the road to Angaqui passes. Angaqui is a Christian village, situated on a knoll of coralline limestone on the left bank of the Abra. From Angaqui we crossed the coastal cordillera through Tovalina Pass at an elevation of about 3,500 feet. One of the most striking peaks of the range at Angaqui is Mount Tila, which because of its needlelike form reminded me very much of the Peter Bott in Mauritius.

Up to the pass the cordillera consists of a beautiful, partly crystalline, coralline limestone. The innumerable coral fragments are in a very poor state of preservation.

Very soon, however, after having reached the greatest height, which gives a splendid view of the ocean, on the steep western slope, there appear very thinly stratified, reddish, tufflike marls dipping south-southwest. They contain layers with carbonized plant remains. At Tianagan, the middle point of one of the auxiliary departments of the military district of Lepanto, these tuff-marls are very much folded and faulted. At Cayan I heard that coal had been found at Angaqui, but no one at this place knew anything about the occurrence. It is possible that it lies in a formation similar to the tuff-marl.

Throughout the country between Tianagan and Lilidda these tuff-marls occur alternating with thick strata of coralline limestone; one reaches the plain at Nueva Cobeta and proceeds to Santa on the seacoast. The coast at this point, several meters above high tide, consists of raised coral reefs which are still in contact with the growing coral. The massive rocks which occur in place in the vicinity are composed of quartz, orthoclase, and chlorite.

The city of Vigan, the second largest settlement on Luzon, is situated on a sandy, gravelly plain formed by the delta of Abra River. Abra River, as a whole, follows a north to south direction; east of Bangued, the capital of the military district of Abra, however, it turns suddenly to west-southwest, breaks though the coastal range in a narrow chasm at a point called the Bocada, about an hour's journey east of Vigan, and then divides itself into several branches, which rush toward the ocean through shifting channels. The Bocada, to which I made a little excursion, is cut into a complex of clearly stratified rocks, which as a whole show a steep westward inclination. This bedded series is composed of two kinds of rocks, frequently alternating with each other. One is a much crumpled chlorite schist closely traversed with calcite veins; the other rock is coarsely crystalline and is somewhat similar to a protogine gneiss like the rock we have already noted at Santa. For about one-half mile the river courses through this region of crystalline schist in a very narrow bed. At San Quentin the valley broadens, and one enters the district of Abra.

In order to reach Manila from Vigan, I boarded a steamer which went around the northwest point of Luzon to Lallo, on Cagayan River, took on tobacco there, and then without stop steamed to Manila. An opportunity was, therefore, given me to see, even though but hurriedly, the mouth of the Rio Grande de Cagayan. It is uncommonly broad and flat, and numerous sand banks which change their position each year after the rainy season make navigation difficult. It is possible to go as far as Tuguegarao, the capital of Cagayan Province, by using very light-draught steamers. It is to be hoped that the Spanish administration, which recently has been disposed to pay greater attention to this fine colony, will open the river, which is an important and beneficial artery of transportation for the tobacco district, by regulating and controlling its channel. At Lallo I found the banks of the river to be constituted almost entirely of heaps of *Anodonta* and *Unio* shells.

If we now review the observations made during my journey through northern Luzon, we shall distinguish five important groups of rocks: (1) The coral reefs and breccias of coralline limestone with recent volcanic rocks; (2) the tuffs and tuff-sandstones associated at places with coralline limestone beds and marls with plant remains; (3) recent eruptive rocks (quartz-trachyte, sanidine-hornblende-trachyte, hornblende-andesite, and dolerite); (4) the Agno beds, a mighty system of coarse sandstones and conglomerates, which have been derived from the underlying diabase and aphanitic rocks; and (5) diorite, protogine gneiss, and chlorine schist.

There can be no doubt that the coralline limestones belong to the most recent rocks occurring in northern Luzon. They always form the uppermost member of all formations, and with the exception of Benguet, where they are covered with a thin layer of red earth, I failed to find these limestones beneath other rocks. As has been said, they contain a number of coral fragments which, unfortunately, are in a poor state of preservation; they contain, although only in limited numbers, remains of lamellibranchs, gastropods, echinoderms, etc. All of these fossils have, however, suffered very much on account of the crystallization of the limestone. My highly honored friend, Mr. Neodor Fuchs, curator at the Imperial Cabinet in Vienna, at my request conducted an examination of corals occurring in the coral reefs of northern Luzon, as well as of the similar coral obtained at an earlier date in southern Luzon, and has reported his results as follows:

"The corals in question occurring in the limestone of northern and southern Luzon are in a condition of preservation that reminds one of our nummulitic limestones, so that according to European occurrences the specimens might from their outward appearence be considered at least as old as the Eocene."

A more extensive examination of the same material undertaken by me in conjunction with my honored friend Doctor von Marenzeller, in charge of the collection of the Zoölogical Court Cabinet, led also to substantially the same results.

Even though it was impossible to give a reliable specific report on account of the poor state of preservation of the fossils, it nevertheless was possible for us to declare with certainty that, with the exception of one single piece, which we could not identify, all of the rest belonged to genera which occur to-day in great abundance in the Indian Ocean, and even the individual corals can be referred without any question to living types. The corals examined do not show the least relationship to the Tertiary corals from Java described by Reuss.

Regarded from this point of view, the raised coral reefs of Luzon must be considered as very recent in origin.

The genera identified by us are the following: *Galaxaea* sp., *Favia* sp., *Maeandina* sp., *Porites* 2 sp., (?) *Astraeopora* sp.

The stratigraphic as well as the palæontologic results go to show that the raised coral reefs of Luzon belong to the most recent geologic formation. One of the most noteworthy features of these reefs to my mind and at the same time a feature of highest geologic significance is their perfect stratification; how this stratification came about remains unanswered. I have seen similar coral reefs on the western coast of Luzon which were lifted only a few feet above the level of the sea; these showed the same peculiar property, which von. Mojsisovics has designated *übergossene Schichtung* in describing the Alpine coral reefs.

May not the stratification of the coral atoll of Benguet be attributed to a periodic cessation of the growth of the reef, perhaps caused by volcanic activity in the vicinity? I can scarcely accept the view that the stratification took place later, induced by metamorphism.

I bring this point into prominence, because Gümbel (Sitzungsberichte der mathemat.-physik. Classe der k. k. Akademie der Wissenschaften zu München, 1873, 3, 71–76) finds reason to deny the coral-reef nature of the *Schlerndolomiten* in the fact that they are stratified. Gümbel mentions the rare occurrence of thin layers of marl in the Schlerndolomit. I noticed, as was mentioned on page 39, very similar occurrences in the reefs of Sagada. Gümbel finds another argument against the coral-reef nature of the Schlern in the very rare occurrence of coral remains. We have seen how the geologically recent reefs of Luzon have been partly transformed into crystalline limestone. Even though it is indeed a peculiar thing that *Gyroporellen* are preserved very excellently whereas hardly anything is to be recognized of the corals, this should not be sufficient evidence to doubt the reef nature of the Schlern. Von Mojsisovics, on the other hand, defends the reef nature of the Schlern as follows:

"There can be no serious objection to the reef origin of the Schlerndolomit so long as we have no more than our present knowledge of the genesis of the lamination and stratification of homogeneous rocks." (Faunengebiete und Faciesgebilde der Triasperiode in den Ost-Alpen, Jahrb. der k. k. geolog. Reichsanstalt, 1874, 96.)

Semper has pointed out the rapid transformation of reefs into crystalline limestone and the noteworthy preservation of the structure in older corals. His remarks on page 100 of the second sketch, "The reefs and life in the Ocean," are worthy of great attention.

The most important facts, therefore, lead us to consider the entire Philippine Archipelago as being in a state of continuous elevation. The raised coral reefs still in contact with the living ones, to be found at all points on the coasts, as well as the geologically recent reefs at an elevation of 4,000 feet in the military districts, are examples which speak enough for themselves. In the Archipelago of the Philippines there are yet to be found living atolls, the growth of which, according to the theories of Darwin and Dana, must have been contemporaneous with a sinking of the ocean bottom. This data led the untiring Forscher to a closer examination of this question. From the observations of Carpenter on the coast of Florida he holds that the formation of coral reefs is possible even from great depths and explains the different ways of emergence, by the influence of currents and other factors.

The presence of coral reefs elevated to a considerable height is not peculiar alone to those regions in the Philippines visited by me. Semper also mentions similar occurrences in northern and eastern Luzon and in Mindanao. Junghun also speaks of elevated coral reefs on the southern coast of Java.

The greater part of the tuffs and tuff-sandstones are unquestionably older than the raised coral reefs. These tuffs, even though we admit excessive faulting and folding, of which I could find no clear evidence, however, are extraordinarily widespread. From Aringay to Benguet, which has an elevation of 4,000 feet above sea level, they occur without interruption and likewise from Nueva Cobeta almost to the western slope of Tovalina Pass (nearly 2,000 feet). The included coral strata point to extended periods of rest in the formation of this complex, whereas the remains of dicotyledonous plants in the marls indicate the nearness of land. The coal measures of Angaqui and Aringay, which I did not examine personally, may very possibly form part of the same formation. In the basal rocks of northern Luzon, finally, we must include the Agno beds: diabase, gabbro, syenite, diorite, aphanite, and the protogine gneiss, which perhaps is the oldest of all. That the Agno beds have derived their material principally from the underlying greenstone and are, therefore, younger than the greenstone has already been mentioned.

It is highly interesting that a very similar bedded complex has also been found by Minard on the Island of Mindanao; it appears that in Mindanao these rocks are the source of gold (Sur les gisements d'or des Philippines, Bull. de la Société géolog. de France, 2, 3d series, 403). The gold is obtained from the gravels which the Rio de Iponan carried down from the interior, as well as from steep alluvial terraces which lie at the bases of the mountains. The most important rocks which are met with in Iponan Valley, according to Minard, are conglomerate and various kinds of sandstones with calcareous cement, covered over at many places by coralline limestone. The strata are broken through at numerous places by diorite and serpentine, and their inclination is about 12°. The stratigraphic order of these rocks is as follows: Shale (thickness unknown); conglomerate derived from various classes of rocks (thickness, 100 meters); grit derived from various classes of rocks (30 meters); argillaceous coralline limestone (30 meters); laminated clay (15 meters); ancient alluvium not gold-bearing (10–12 meters); recent gold-bearing alluvium (6–8 meters). The conglomerates are composed of the following kinds of rocks: 1, Black, coarsely laminated amphibolite; 2, diorite, with large amphibole crystals and triclinic feldspars as essential minerals and pyrite, quartz, and epidote as accessory minerals; 3, some specimens intermediate in character between the amphibole-diorite and the amphibolite-diorite of medium-grain size; 4, granitoid diorite with much mica; 5, aphanite; 6, granular marblelike feldspar in which granite and amphibole occur in bands; 7, serpentine diallage (magnetic), variety of ophiolite; 8, precious serpentine with asbestos veins; 9, diorite porphyry; 10, augite porphyry; 11, quartzose epidote; 12, jasper in beautiful modifications.

The gold-bearing alluvium is found in greater or lesser degree upon all the sedimentary formations enumerated, but principally on the conglomerate.

Here, as in northern Luzon, the dioritic-syenitic rocks are the gold-containers. The alluvium contains large quantities of mica, and according to Minard three native metals: gold, platinum, and lead. Daubrée noted the presence of zircon in the washed sand, which again points to syenite as the probable origin.

So far as concerns the relative ages of the different recent eruptive rocks it is impossible to determine anything with certainty. The eruption of all of these rocks may have taken place during the period of formation of the tuffs; and there is no evidence that the eruption of volcanic masses did not continue even after the elevation of the reefs. The still active solfatara of Aknal and the hot springs of Bontoc are the last stages of this wonderful phenomenon, which, perhaps, reached its greatest activity in the vicinity of Mount Data.

We are, therefore, led to conceive of the west part of northern Luzon as having consisted at one time of a mountain range of crystalline schist, which was elevated by mighty diabase and syenite eruptions, the fragments of which later were stratified into great sandstone and breccia-complexes. A long period of time perhaps elapsed between the deposition of the Agno beds and the renewed manifestation of volcanic activity. With the later vulcanism there were deposited large masses of tuff on the west coast; there must have been a contemporaneous subsidence of the sea floor to permit the deposition of such a great thickness of detritus. During the intervals of quiescence, even though of short duration, the corals could carry on their reef building. Vegetable remains transported from the mainland formed the plant-bearing marls. Even before the end of this period of subsidence it appears that volcanic activity had ceased. On the extensive submarine platform of tuffs the coral polyps built their structure and formed the coral reefs along the mainland which we now recognized in the Sierra Tovalina and in the detached peaks on the left bank of the Agno. Farther out in the sea atolls were formed, one of which we still find preserved in an excellent state in the valley of Benguet [Trinidad Valley].

An accurate knowledge of all of these individual reefs would enable us to make a correct estimate of the form of the mainland in those times, which apparently consisted of narrow islands having a north-south direction. Finally there began the period of elevation, which still continues, and which, judging from the age of the reefs, must pertain to a geologically recent period. The effect of this process of elevation was to join together the different islands as a related whole, in which we can easily distinguish, through the form of the land and the consequent direction of flow of the rivers (Abra, Agno, and Pan), a row of folds with north-south axes attaining the imposing height of 4,000 feet. This is unquestionably a very remarkable change of level within so short a time.

The Abra eroded its bed in the former channel between the mainland and the present coast range, the Sierra Tovalina, and utilized the large transverse cleft at Vigan to reach the sea. The two parallel-flowing rivers, Pan and Agno, may have flowed into the ocean-covered plains of Pampanga and Pangasinan at Niyong and Sto. Niño in very recent geological time. Only after these plains had been lifted out of the ocean, an event that may have been one of the last in the geologic history of Luzon, did they swerve westward and follow the gentle slope of the plain.

This might be, in very general terms, the geologic history of the western part of northern Luzon.

At the end of this monograph I shall try, in a summary, to correlate the formations noted on Luzon with those of Java, the only island in the Indian Ocean whose geology is thoroughly known.

GEOGRAPHY

TOPOGRAPHY

This region is typically mountainous, and from the character of the relief we must consider it as being in the stage of "topographic youth," as a glance at Plate II, which is characteristic, will at once make evident. Whatever might be said in general elucidation of this type of topography has already been said and written many times about similar forms of relief in geologically young parts of the earth and would only mean needless repetition here. However, a few facts should be noted.

There are two distinct types of topography in the region covered by this paper, and these are directly to be attributed to the character of the geologic formations. In the country to the west of the Polis Range the formations are mainly volcanic, and we find there an irregular, rugged, accentuated relief. The elevations vary from 370 meters to 2,400 meters or more.

East of this range the formations are folded sediments, giving rise to a more regular topography, and in places the hills and mountains are nothing more than tilted blocks of sandstone. On the eastern slopes these present long, gentle inclines, but to the west they form steep escarpments with here and there a saw-toothed skyline. As one goes farther to the east, approaching the valley of the Cagayan, the mountains become mere foothills.

Cagayan Valley, which I have not personally explored, though I have overlooked it from a number of points, is clearly synclinal.

In the eastern portion, between the high and low country just referred to, there is a stretch which has been called by Worcester "No Man's Land." The people inhabiting this tract will be referred to in a subsequent paragraph. The topography consists of medium-sized hills, from 370 to 430 meters in height, which are due to a cross folding of the originally flat-lying sediments. This cross folding produces hummocky hills and little pockety valleys or hollows.

CLIMATE

The climate of this region shows a complete gradation from subtropical in the bottoms of the large valleys, as, for instance, at Cervantes, to temperate in the more elevated portions. The lowest temperature that I experienced was at 5.30 on the morning of March 11, 1914, on the summit of Mount Amuyao, 2,700 meters' elevation, when the thermometer registered 7°.8 C. At Bontoc, 945 meters' elevation, the temperature reaches this point in January.

As to the rainfall I can only say that at certain seasons (June to October in Bontoc and Kalinga) it is at times excessive, but the season differs in the several subprovinces. Again we find the Polis Range the great dividing line. On the eastern and southern side of this prominent topographic feature, in Ifugao, for instance, the seasons correspond more nearly to those which are found to obtain in the Cagayan Valley.

HYDROGRAPHY

The prominent features of the hydrography are the two principal streams, the Abra, rising on the slopes of Mount Data, flowing almost due north approximately to the town of Dolores, where it turns west by south and cuts through the coast range just south of Vigan, and the Chico which flows northeast and finally reaches the sea by way of the Cagayan. Neither of these streams is navigable in the area under discussion in this report. The main drainage in this area, then, is along well-defined, and doubtless structural, north and south lines with, of course, the usual attendant tributaries, which are influenced by purely local and minor topographic features.

VEGETATION

The region as a whole cannot be said to be a forest region. There are areas, such as those on the slopes of the Polis Range, which are fairly well-forested, chiefly with pine (*Pinus insularis* Endl.). There are other parts of the territory clad only with scattered timber, little of which is suited for anything but fuel, as around Bontoc and Lubuagan, while in Ifugao, particularly around Banaue, there is scarcely a stick of standing timber.

There is, of course, to be noted the usual vertical differentiation in the plant distribution quite constant throughout the Malayan province—that is, tropical flora at the lower elevations; from 760 to 1,830 meters, usually pine (not always, however); above this, the so-called "mossy forest;" and finally on the highest points only grass. The reader is referred to Merrill's[3] article on the flora of Mount Pulog, the highest peak in Luzon, situated just to the south of the country explored by me. What Merrill found on that mountain, I think, is typical of northern Luzon.

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[3] *This Journal, Sec. C* (1910), 5, 287–370; 371–403.

The extreme low-country vegetation we no longer find anywhere in this region. This is important to bear in mind in connection with the fossil flora recently found at a high altitude and to which reference will be made on a subsequent page.

PEOPLE

The indigenous peoples of this northern country are essentially primitive and in most instances have been little influenced by outsiders. While a considerable number of tribes and corresponding dialects have been noted, they are ethnologically fairly homogeneous. It will suffice here to refer the reader to such authorities as Worcester[4] and Jenks[5] for fuller treatment.

GENERAL GEOLOGY

GENERAL STATEMENT

A cross section from the west coast at Tagudin northeastward to the edge of Cagayan Valley gives as good a general idea of the formations and structure of the region as one could expect to get by any procedure short of a detailed survey of the whole country. Fig. 2 is a graphic attempt to record my interpretation of the main facts.

Near the west coast we find gently folded shales and sandstone whose inclination increases as we go toward the Malaya Range, being much contorted as we get well into the cañon. The Malaya Range is essentially a mass of porphyry or, to be more exact, andesite. Some phases of it are aphanitic and are distinctly bluish green, indicating perhaps disseminated copper.

The town of Cervantes is situated on a small tongue of high ground between the Abra and one of its branches. The underlying rocks are practically the same as those found in the highland on both sides of the town. As we go toward Bontoc we find the same andesitic mass with, however, several large outcroppings of quartz.

When we reach Baguan and Sagada we find tuffs and reef limestones overlying this igneous mass. These tuffs dip 20°+ to the southeast, and although they are topographically higher than the limestones, in places the limestones lie stratigraphically above the tuffs. Subsidence of limestone would explain this.

From Sagada to Bontoc extrusive rocks, almost entirely an-

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[4] The non-Christian tribes of Northern Luzon, *This Journal* (1906), **1**, 791–875.

[5] The Bontoc Igorot, *Pub. P. I. Ethnol. Sur.* (1905), **1**.

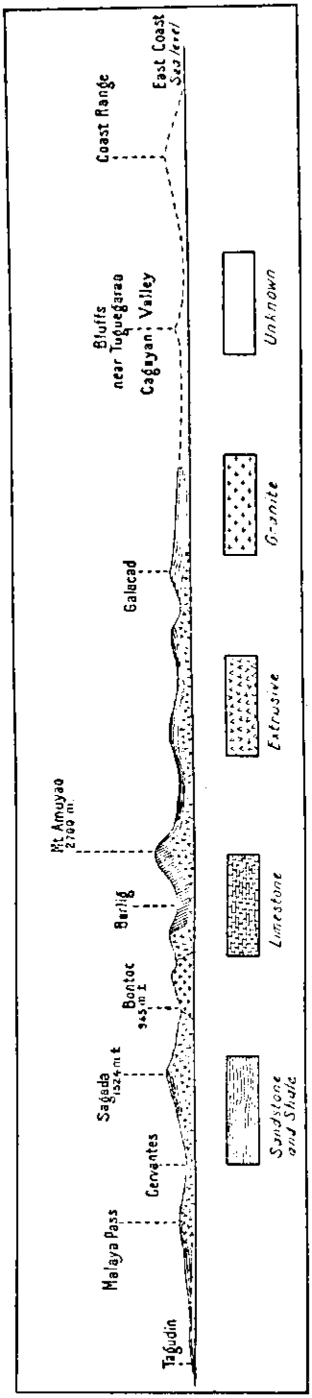

FIG. 2. Generalized geologic section across northern Luzon, from Tagudin to the eastern coast.

desites and dacites, are encountered but east of Bontoc the formation becomes very shortly diorite and granite. This belt of granitic rocks is only from 8 to 10 kilometers wide. There is more andesite, or rather a very fine-grained, almost aphanitic phase of diorite, succeeding the granite on the east as far as the town of Barlig, where steeply dipping sandy shales are encountered. These incline to the southeast.

Sandstone makes up the main mass of Mount Amuyao, and from there east to Cagayan Valley sediments occur. In places, as at Natonin, there are small areas of extrusive rocks overlying the Tertiary sediments. No limestone was seen east of Barlig, but farther north on the crest of the range east of Tinglayan I could detect limestone cliffs with the aid of a binocular. They are nearly 2,200 meters in elevation.

The apparent structure of the sediments in the eastern part of the section is indicated in the diagram.

THE PLUTONIC ROCKS

The plutonic rocks consist of granite and diorite.

The granite.—This formation was found at two points, a short distance east of Bontoc and in the Saltan Valley. It appears to be a long intrusive mass, whose axis runs from northwest to southeast. It is a typical quartz-feldspar-biotite granite and has a grayish to glaring white appearance in the field. The feldspars are milky white. No microscopic examination of the feldspar has been made. The joining in this formation is particularly marked.

The diorite.—The diorite is a quartz-plagioclase-hornblende variety with some orthoclase and lies on both sides of the granite. Bordering the granite, and apparently in the diorite, are several large quartz bodies, which will be referred to again. These plutonic rocks are undoubtedly very much more extensive than they appear to be, but are concealed by the overlying extrusives.

The diorite I consider to be the basal formation, although it may subsequently be found to be intrusive as well. I regard the granite as an intrusion of rather recent date, equivalent to the late intrusion in the Paracale district farther south.

THE EXTRUSIVES

Von Drasche has already described the typical extrusives found in this region, and I have little to add to his list. However, he does not make any mention, I believe, of the occurrence of dacite, a glaring white rock with small phenocrysts of clear quartz in a dense, creamy white aphanitic groundmass. I found this well developed near the junction of the main Cervantes trail and the Sagada trail at kilometer 6, south of Bontoc. Its relation to the rest of the extrusive mass, which is andesitic, is difficult to make out even in the fresh cliffs along the trail. It may be an intrusive. It is not essentially different from the Corregidor rock.

There were undoubtedly several vents from which these extrusives issued, and one of these seems to be clearly indicated in a sort of broken-down craterlike topographic feature west and north of the town of Bontoc. The presence of tuff beds near the town dipping away from this center seems to bear out this supposition. Fig. 3 is a sketch of Bontoc and vicinity, showing the relationships obtaining there.

The list of extrusives, compiled both from von Drasche's and my own observations, includes: basalt, pyroxene-andesite, hornblende-andesite, andesitic agglomerate, dacite, and tuff.

A description [6] of the extrusives in the Benguet region applies essentially to the extrusive rocks farther north.

THE SEDIMENTARIES

The sedimentary rocks in this region include the following: Limestone, marl, tuff, tuffaceous sandstone, sandstone, shale, conglomerate, calcareous and siliceous sinter, and travertine.

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[6] Smith, W. D., *This Journal, Sec. A* (1907), 2, 235.

Limestone.—Limestone in the high mountain region of Luzon is widespread though not necessarily extensive. It is manifested by remnants here and there, generally on the high mountain tops, and by "float" in the streams. One is led to believe that it formerly extended over practically the entire country.

The most extensive development of it is probably at Sagada, where we find it projecting from the soil and talus in great masses as shown in the photograph (Plate IV). The bedding planes, which can be distinctly made out even in the picture, dip about 20° southeast. On the weathered surfaces the stone is bluish gray, but on fresh fracture it is cream white to reddish. Plate IV, fig. 2, shows the characteristic spirelike forms produced by the dissolving action of the heavy rainfall of this region.

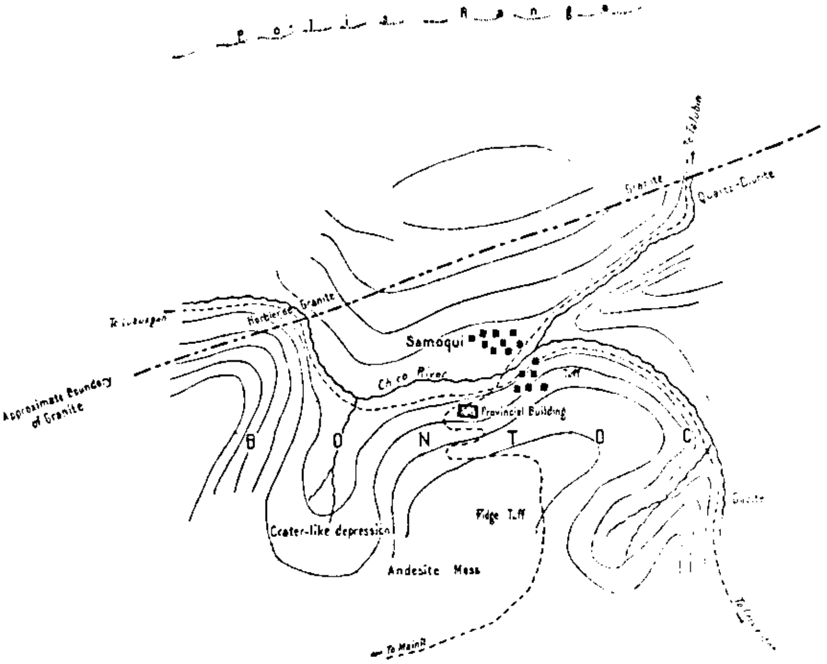

FIG. 3. Sketch of the vicinity of Bontoc.

A thin section of the rock shows innumerable fragments of the well-known Mio-Pliocene marine alga, *Lithothamnium ramosissimum* Reuss. This formation, therefore, is equivalent to the upper limestone in Cebu and many other parts of the Archipelago.

In this limestone at Sagada are numerous sinks and some caves. In the entrance chambers of the caves the Igorots place their dead. One cave has a chamber as large as the auditorium of a small theater and is said to have passages several kilometers in length. I made no extensive exploration of these, as I felt that this was purely a side issue, having no fundamental bearing on the more general field studies then in hand. Cave exploration in this region would probably not yield any paleontological results as the amount of water carried through these passages at certain seasons would undoubtedly remove any such remains.

In another way their exploration is of practical value. For instance, near Baguio just the same sort of cavernous limestone, in places concealed by the tuff and talus, has been responsible for some very serious slides along the Benguet road. And, also, at Sagada I think the limestone must be held responsible for some rather extensive landslides.

In traversing the hills about Sagada (just south of the mission), I found a conglomerate of apparently purely local development above the limestone. It consists of a sandy and reddish matrix with limestone pebbles in it. This conglomerate is not to be correlated with the "Agno beds," which are far below both topographically and stratigraphically.

Marl.—Von Drasche has already called attention to the marly layers intercalated in the upper limestone near Sagada. These can be seen in several places in the road south of the Mission, but they are only thin layers and are not of any economic importance. The marl is buff-colored.

Tuff.—As would be expected in a region of formerly great vulcanism, tuff beds are a dominant feature of the sedimentaries. At Sagada, where Father Staunton, of the Sagada Mission, has opened a quarry to secure material for his new church, is perhaps the best section of the tuff beds to be seen anywhere in the province. The face of the quarry is about 15 meters high and reveals the following beds:

1. Soil and loose material.
2. Tuff in heavy beds, 1.5 to 3 meters.
3. Yellow-stained shale, 0.5 meter.
4. Tuff in solid bed with varying texture, 18 meters.
5. Bluish black shaly-looking rock which is very fine-grained, 1 meter.

In this section the strata appear to be nearly horizontal, as the face is approximately along the strike. The dip is about 20° to the southeast. In the shaly portions are great numbers of leaf impressions, some fine specimens of which I secured through the assistance of Mr. McBrust, the engineer of the Sagada Mission. These leaf impressions are so perfect and so much like some of the living lowland plants that I submitted them to

Mr. E. D. Merrill, botanist of the Bureau of Science, for identification. His illuminating notes are inserted here:

> The fossil remains, mostly remarkably clear leaf impressions, all, or nearly all, represent species still living in the Philippines at low and medium altitudes, and an examination of the material shows that the forest in the Bontoc locality was a typical mixed dipterocarp forest such as is found to-day in all parts of the Philippines, where primeval vegetation persists, from sea level to an altitude of about 800 meters. None of the species is found to-day within the limits of Bontoc subprovince, and very few of them are to be found in any part of Mountain Province. None of them is found above an altitude of approximately 800 meters, while the present altitude of the fossil-bearing strata is 1,500 meters.

DIPTEROCARPACEAE

SHOREA POLYSPERMA Merr. (Tanguile).

Impressions match leaves from living trees beautifully. Throughout the greater part of the Philippines at low and medium altitudes, ascending to about 700 meters. Common. Endemic.

SHOREA GUISO Bl. (Guiso).

Throughout the greater part of the Philippines at low altitudes, abundant. Ascends to at least 500 meters. Endemic.

SHOREA sp. (may be *S. eximia* Miq.).

Like the preceding, but less common. Malaya.

ANISOPTERA THURIFERA Bl. ?

Widely distributed at low altitudes. Endemic. The identification must be considered doubtful, but it is certainly a dipterocarp.

LAURACEAE

BEILSCHMIEDIA CAIROCAN Vid. (Cairocan).

Widely distributed in the northern and central Philippines at low and medium altitudes. Ascends to perhaps 500 meters. Endemic.

PHOEBE STERCULIOIDES Mess.

Like the preceding, but in all or most parts of the Philippines at low altitudes. Ascends to 500 meters.

GUTTIFERAE

CALOPHYLLUM BLANCOI Pl. & Tr. (Palo maria del monte).

Widely distributed in the northern and central Philippines at low and medium altitudes. Ascends to 600 meters. Endemic, unless the same is a Malayan species.

TILIACEAE

DIPLODISCUS PANICULATUS Turcz. (Bolobo).

Throughout the Philippines at low altitudes, ascending to 500 meters. Common and abundant. A monotypic, endemic genus.

MENISPERMACEAE

ANAMIRTA COCCULUS W. & A. (Suma).

Widely distributed in the Philippines at low and medium altitudes. India to Malaya.

CYPERACEAE

MAPANIA HUMILIS F.-Vill.

The identification is not certain. The species is found throughout the Philippines in mixed forests from sea level to 600 meters and is abundant locally. The impression may be that of a leaflet of *Calamus* sp. (Palmae).

INDETERMINABLE

Cast of a fruit that conceivably may be that of a more or less distorted *Pterospermum* (Sterculiaceae).

Faint impression of a crushed stem or a monocotyledonous leaf. Quite indeterminable.

Imperfect remains of several other kinds of leaves, the material quite indeterminable.

These tuff beds are in all likelihood equivalent to the great series of tuff beds in Java in which *Pithecanthropus erectus* Du Bois was found, and which were once thought to be Pliocene, but have recently been shown by Schuster[7] to be Pleistocene. Schuster bases his conclusions upon the plant remains inclosed in the strata. Special attention is invited to Plate XXVII of Schuster's work, where a graphic section of the tuff strata exposed at Trinil is given.

The conclusion to be drawn from the presence of these fossil leaves is clearly that there has been very recent and very pronounced elevation in this part of Luzon. It does not argue a change in climate in the Philippine region other than that attendant upon a change of elevation. All the evidence we now have points to the fact that there probably has been little or no regional change in climate throughout the Tertiary and Post-Tertiary in this part of the world. The fact that the nipa palm, now growing in the Philippines, is found fossilized in the London clay (Miocene) indicates that essentially Tertiary conditions still prevail in this part of the world.

In 1911 there was a landslide of considerable extent in this region, due probably in part to the tuff and in part to the limestone as indicated in the diagram in fig. 4. The subsidence amounted to as much as 15 meters in places and carried the entire village of Ambasing with it. The line of the fault can still be seen on the hillside. The area affected is about 2.5 square kilometers.

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[7] Schuster, Julius, Monographie der Fossilen der Pithecanthropus Schichten, *Abh. d. k. bayr. Akad. Wiss.* (1911), 25, Abh. 6.

Tuffaceous sandstone.—Throughout this region, but particularly near the volcanic area, are beds which can with difficulty be differentiated from tuff on the one hand and true sandstones on the other. This material is found in its most puzzling aspect at Lubuagan, the capital of Kalinga. The truth of the matter is that the constituents of both the tuff and the sandstone came from the disintegration of volcanic rocks. Whether they were derived from material blown out by explosion or by subsequent erosion can only be told by examination of the shape and condition of the component grains. The point is that the constituents in both cases may be much the same. As one goes eastward it becomes easier to make these distinctions.

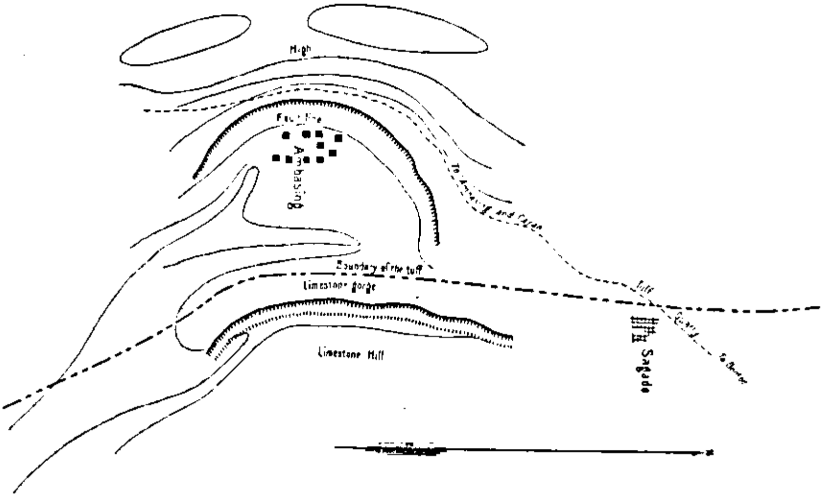

FIG. 4. Sketch showing slide near Sagada.

Sandstone.—A typical exposure of what might be termed the Kalinga sandstone is found on the banks of Chico River near the Nipon resthouse. At this place the sandstone and alternating shale beds are exposed for almost a kilometer on the west bank of the river. The dip of these beds is 65° and a trifle to the north of west. The sandstone is a coarse, grayish to buff material, which shows plainly its derivation from andesitic rocks. Along the bedding planes ripple and wave marks are very plain and abundant. There also was seen an impression apparently made by a long-stemmed reedlike plant. Unfortunately this specimen is too imperfect for identification. It is possibly the remains of a gigantic sea weed, or a reed which grew in brackish water or in the swamps near the sea. No animal remains were found in this exposure, but at a road camp along the trail between

Lubuagan and Sician, in the sandy shale portions of what must be the same series, I found the following forms:

Turbo borneënsis Bttgr. (?).
Pecten senatorius K. Mart.
Pecten leopardus K. Mart.
Cardium sp.
Conus sp.
Cycloseris decipiens K. Mart.
Cassidaria sp.
Tapes sp.
Dosinia sp.
Turbinella tjidamarensis K. Mart.
Fragments of Alcyonaria.

The presence of these fossils stamp this formation as Mio-Pliocene.

Shales.—The shales which are found intercalated in the sandstones of this region grade imperceptibly into them. Mineralogically they are the same and differ merely in grain size. Plate V, fig. 1, gives an excellent idea of their field occurrence. The thickness of these beds would in the aggregate amount to from 300 to 600 meters. The repeated alternation of sandy and shaly layers in practically all of the sections, but particularly in this one, indicates that these beds were laid down in shallow water.

The cliff shown in the photograph is one of the most dangerous on the trail between Bontoc and Lubuagan, due to the crumbling nature of the beds, together with the inclination, which is approximately 45°. No fossils have been found here.

The conglomerate.—I have alluded already to a local conglomerate associated with the limestone at Sagada, but the one I shall refer to now is the basal conglomerate equivalent to the "Agno beds" of von Drasche. It does not appear to be developed to the extent of the beds in the type locality on Agno River or along Bued River. This formation is mineralogically the same as the sandstone and the shale, the difference again being one of grain size. Naturally we find andesitic and dioritic material predominating, as these rocks predominated in the ancient headlands of the Tertiary seas. It is very easy to confuse some of the conglomerates with the volcanic agglomerates. Also the sandstones, in places, through concentric weathering, simulate the conglomerates. I have no idea at present of the thickness or extent of these conglomerates.

Sinter.—In this region hot springs are occasionally found where great quantities of siliceous and calcareous sinter are to be seen. At Salinas, in Asin Valley, one finds the best and most beautiful deposits (Plate V, fig. 2). At Mainit, near Bontoc, there are terraces, but the Balotoc hot spring deposits practically no sinter.

Travertine.—We cannot omit from a complete list of sedimentaries the ubiquitous deposits of travertine here and there in the streams, attesting the presence of a limestone remnant somewhere farther upstream. As pointed out in discussing other parts of the Archipelago this deposit is found most abundantly on shale, and wherever it occurs it completely obliterates the rocks beneath.

STRUCTURE

The generalized cross section will give a clearer idea of the structure in the province than any amount of description.

Considering northern Luzon broadly, we note on the extreme east an anticline (presumably—I have no specific information concerning the structure of the eastern cordillera) with the Cagayan syncline, or trough, immediately to the west. From this trough the sedimentaries rise gradually, with minor folds, in a long monocline until they abut on the igneous complex of the Cordillera Central. To the west of the cordillera is the long tectonic trough occupied by Abra River. It is not yet proved whether this is a rift valley or not, but certainly it has a strong resemblance to one. As much of the country has been covered with volcanic ejecta, it is difficult without more field work to discuss the structure in many parts of the region.

It is not unlikely that there was a broad, gentle arch of younger sediments, chiefly limestone, over the Cordillera Central, judging from remnants of this formation on the crests of some of the highest ranges, but even here the evidence is not sufficient. Eveland[8] has already suggested this.

In conclusion, we may say that the grain (to use a word employed by Professor Gregory, of Glasgow) of northern Luzon is north and south, as we would expect from a glance at the alignment of its topographic features alone. Many irregularities in strike and dip with faults complicate the study of the region.

GEOLOGIC HISTORY

It is a question whether any one has done enough geologic work in this part of Luzon to give other than suggestions of the geologic history. Von Drasche does not say enough about the sediments in this region, undoubtedly because he did not get far enough eastward to encounter them. Not only was there a long period of subsidence, but this was interrupted by minor oscillations of level as indicated by the rapid change in the character of the sediments. He says nothing about the great

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[8] *This Journal, Sec. A* (1907), **2**, 207.

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earth movements as indicated by the present folded condition of these sediments.

One would get the impression from von Drasche that considerable quantities of plant remains are to be found in the marl beds. I found none in the marl, but all were in the tuff beds. I saw no schist in that part of the area I explored.

ECONOMIC GEOLOGY

The economic portion of this report will of necessity be brief. The semiwild state of most of the territory and the comparatively untutored condition of the people, of course, precludes any but the most rudimentary utilization of the mineral resources. In the following discussion I shall consider not only the useful minerals known to exist but some possibilities as well.

NONMETALS

Clay products.—There are undoubtedly many localities within this territory where both residual and transported clays can be obtained. Pottery making is here, as throughout the Philippines, a household industry. The chief locality for its manufacture is at the town of Samoqui, just across the river from Bontoc. The clay is very poor and sandy and burns red. There is some attempt at decoration, and there is a slight glaze given to the pots by the use of resin, if I am correctly informed. This industry has been described by Jenks.[9]

On the Bontoc side a fair grade of red brick is made by Igorots under the superintendence of Americans. All of the public buildings of the capital of the province have been constructed of this brick. The industry was started by John Early, formerly a school-teacher stationed at Bontoc. The effect of these brick structures is a very pleasing one. Apparently there have been no earthquakes of sufficient importance to cause any damage, and with the exception of this danger this type of construction seems to be excellently adapted to the country.

Sand-lime brick could easily be made in many localities in this section. The principal cost would lie in the generation of steam, and the manufacture might not be economical on that score.

Coal.—Thin streaks of coal have been reported from various places in Mountain Province, but I have not seen any that promise to be of commercial value. I believe that the changes in sedimentation were so rapid as to preclude the formation of workable thicknesses of coal. Farther east in the syncline occupied by Cagayan Valley, where quieter conditions prevailed and gradual subsidence took place, coal deposits could and did form.[10]

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[9] Op. cit.

Lime.—As limestone is found at many points in the province, if not always in place, in stream bowlders in great numbers, an abundance of lime could be made. At present practically the only limestone burned is at the Sagada Mission, where Father Staunton has installed two iron kilns of foreign make. As already mentioned, there is an abundance of pure white (and some reddish) limestone belonging to the Pliocene epoch, which makes a very good lime. According to Mr. McBrust a very good hydraulic lime is secured by burning the red variety. The supply is practically all used locally.

Oil.—As yet no oil seeps have been reported from this part of Luzon, but it is not improbable that such may be found in the sedimentary area in the eastern part of this region where the structure is not unfavorable.

Salt.—The three best-known salt springs in this region are, beginning at the south:

1. Salinas, located in the Asin Valley. This has been described by Cox.[11]

2. Mainit, located about 12 kilometers northwest of Bontoc, which has been described by Jenks.[12]

3. Balotoc, located about 10 kilometers east from Lubuagan. The trail to Balotoc is about 20 kilometers long, and the traveling is pretty rough in places. This spring differs very materially from the other two in that in the first two there is a considerable deposit of calcareous and siliceous sinter with a small amount of salt, whereas in the latter there is no appreciable deposition of sinter, but the water as it issues from the spring seems to be saturated with salt. The process of concentrating the salt for use is, therefore, a very simple one, as the natives simply run the water through bamboo tubes into caldrons, where the water is evaporated by boiling. At Mainit and Salinas the operation requires as much as three months, while at Balotoc only a day or so is necessary. The headman at this place told us that he recovered seven packages, of about 5 kilograms each, per week in one caldron.

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[10] Cf. Ferguson, H. G., *This Journal, Sec. A* (1908), 3, 535.

[11] *Min. Res. P. I. for 1911* (1912), 63.

[12] Op. cit.

The country rock at both Mainit and Balotoc is andesite. The water bubbles up at boiling temperature from very small fissures. At the former locality the spring is located in the bottom of a gully and gives rise to a small stream, but at Balotoc the water issues from the bank of Tabia River. In the rainy season the water in the river rises above the vents, and all operations have to cease.

Following are analyses of the two waters made after both had stood sealed for several weeks:

TABLE I.—*Analyses of waters from hot springs, northern Luzon.*[a]

[Figures give parts per million.]

Constituent.	Mainit.	Balotoc.
Silica (SiO_2)	195.0	317.5
Ferric oxide and alumina (R_2O_3)	88.0	85.0
Calcium oxide (CaO)	127.5	867.5
Magnesium oxide (MgO)	1.1	7.1
Sodium oxide (Na_2O)	457.0	8,688.0
Potassium oxide (K_2O)	23.1	1,579.6
Carbonic acid radical (CO_3)	208.2	----------
Sulphuric acid radical (SO_4)	295.4	236.1
Chlorine (Cl)	752.6	11,590.0
Total	2,147.9	23,370.8

[a] Samples collected by W. D. Smith. Analyses by Dar Juan, chemist, Bureau of Science, Manila. Sp. gr. at 33° C., 1.010.

From these we note particularly two things: namely, the great difference in the sodium chloride content of the two waters and the apparent discrepancy in the case of the silica. This is explained by the fact that the silica of the Mainit water is deposited at once and almost before it can be bottled.

It might be asked whether the existence of buried deposits in beds is indicated by these waters. I do not think so, but believe that the action of subterranean waters of some kind on the igneous rocks will account for the presence of these springs. There are, at least, no surface indications of sediments of any kind in the vicinity.

Sulphur.—About 2 kilometers southeast and perhaps 300 meters above and across the river from the Balotoc springs are eight large steam vents from which copious sulphur fumes issue, and deposited about these are several hundred tons of sulphur. It is said that the insurgents had planned a powder factory here during the late insurrection, but it is evident that they did nothing more than talk about it. This sulphur in its present location has no commercial value. There are likewise some small vents near the river 30 meters or so upstream from the salt springs. The whole countryside shows evidence of dying vulcanism.

Road metal.—For the most part the only highways in this country are horse trails; consequently there is at present little demand for road metal, but we can assert with entire assurance that there will never be any dearth of suitable material when it is needed. There is no lack of "trap rock," which term the road engineer employs to designate several varieties of igneous rock. A very good stone for the traffic utilizing it is now used on the streets of Bontoc. It is a whitish rock, some phases of which resemble dacite, and affords a firm, hard, quickly drying surface. It is abundant just south of the town.

Building stone.—Stone for construction purposes is quarried in two localities. One of these is a gray, impure sandstone, derived from the débris of andesitic rocks, which occurs at Kiangan; the other is a tuffaceous sandstone at Sagada. The two are superficially much alike.

At Lubuagan the school authorities are planning to use a similar stone for building a schoolhouse. My opinion, which has been asked for by local authorities, is that this stone, while superficially much like the stone in the other localities mentioned, is really of very inferior quality. It is a grayish, tuffaceous sandstone, fairly fine-grained, in places coarse, and composed of andesitic detritus. The chief mineral fragments are lime-soda feldspars and hornblende with little or no quartz. A block of this stone, with a bearing surface of 11.8 centimeters by 12.8 centimeters, was subjected to a compression test with the result that it yielded at 348 kilograms per square centimeter without giving a cone. In fact it broke along parallel planes, indicating that the pressure had been applied parallel to the bedding planes (there was nothing to indicate beforehand how these lay). Although this figure is low, it is higher than that (329 kilograms per square centimeter) given for a superior sandstone when compressed along the bedding planes. It is reasonable to suppose that the Lubuagan tuff would withstand a greater load if it were applied at right angles to the bedding planes, and it follows that in construction the stone should be laid with the bedding plane horizontal.

The most unfavorable feature of the Lubuagan stone is its tendency to crack and sprawl on exposure.

I have no figures for the Sagada stone, but as it hardens on exposure it ought to serve very well in structures of moderate size. This stone is not a "blue limestone," as it is locally called, but a tuff. It has a decided bluish cast, and considering the ease with which it can be dressed, makes a very suitable building stone.

WATER

Potable water.—The country west of the Polis Range abounds in springs of excellent water, which I have personally utilized, but eastward, in the sedimentary area, the water is not as good. However, whenever the state of the population demands it, good artesian water can be secured there, as the formations are apparently favorable.

Medicinal water.—The hot water at Mainit is said by the natives of that town to be used by them both for drinking and bathing. They assert, also, that they are practically free from diseases of any kind, particularly skin diseases. Certainly the inhabitants of Mainit are in striking contrast to those of Natonin, for instance, where practically the whole population is afflicted with loathsome skin diseases.

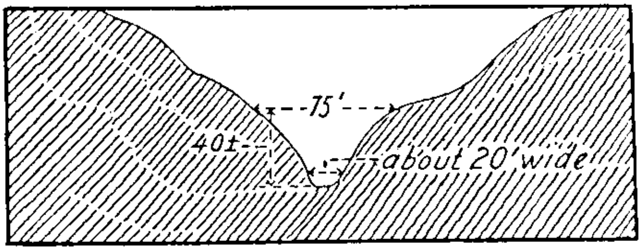

FIG. 5. Profile of box cañon at kilometer 6, south of Bontoc.

What curative effects are derived from the Balotoc water I do not know, but the people living near those springs are likewise free from skin troubles.

Power.—Power sites in this mountainous country and region of bounteous rainfall are, of course, innumerable. At present there is little demand for power. At Fidelisan, just north of Sagada, Father Staunton has constructed a flume from which the water drops 45 meters through a 4-inch pipe to a Pelton wheel, and with the power thus obtained runs a large saw and planing mill. Since storage reservoirs cannot as a rule withstand the tremendous rainfall, the best method of utilizing the streams is by means of diversion weirs and flumes.

However, an excellent site for a storage reservoir, which will be available at some future time for the growing city of Bontoc, is located at kilometer 6, south of Bontoc, at the "suspension bridge." At this point a stream from the west joins the Chico through a fine box cañon in solid andesite. The cross section is about like that reproduced in the diagram (fig. 5).

Above the box cañon the valley widens out, affording a very considerable impounding area. This valley does not appear to be particularly populous, so there ought not to be much difficulty in persuading the people to move to other sites. The dam would be located within a few meters of the main road into Bontoc, and Igorots could efficiently perform all the labor, as they are already skilled in rock work.

METALS

Mountain Province, of course, has one, presumably, very valuable mineral asset in the well-known Mancayan copper deposits. As these have long since received attention from geologists[13] and engineers, there is no need of describing them here.

Northward there are indications of copper, but these are in the Cordillera Central and not eastward, where most of my work was carried on. I neither saw nor heard of any copper deposits in the Polis Range.

Gold.—Eastward from Bontoc, at a point about 4 kilometers distant, granite is encountered, and this continues for several kilometers. As already outlined, this formation extends northward at least as far as Balbalasan. On the western side of this, toward Talubin, I came across several large quartz lodes, outcrop samples of which were assayed, but gave only "traces" of gold. However, as these were only "grass root" samples, it is not conclusive that values are not to be found in the lodes farther from the surface. One of these lodes is about 30 meters wide, striking about north and south, and is nearly vertical. I merely mention these as possibilities for the prospector to look into. The Igorots have never, as far as I could learn, found any free gold in the Bontoc region. It is my opinion, on the other hand, that a granite intrusion like this one will ultimately be found to have caused the deposition of some minerals of value near it. I should not omit to mention that there is more or less iron-stained quartz in Fidelisan Valley near the Sagada Mission sawmill, which has attracted more or less attention from prospectors. Samples taken by me from the face of the ledge gave only a "trace." It is said that the gravel in the ancient banks of this stream about 60 meters above the gorge carries values. It is doubtful if the proposition would be sufficiently remunerative to warrant an expensive installation of machinery.

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[13] Eveland, A. J., *This Journal, Sec. A* (1907), 2, 207.

Iron.—The existence of iron deposits along the Balbalasan trail was reported to me in Lubuagan, but I found nothing but bog ore in the course of deposition at the two places to which I had had my attention called. On the east bank of Saltan River, about 1 kilometer north of Balbalasan, I found a small float bowlder of hematite, but saw no deposit in situ. This locality would hardly be worth prospecting for anything but gold on account of transportation difficulties.

SUMMARY

1. Mountain Province, as its name implies, is for the most part mountainous. The chief valley and place of settlement is the tectonic valley of the Abra. The province is inhabited by semicivilized peoples who live in widely scattered communities, and the town is the chief political unit. Many different dialects are spoken.

2. The geologic formations west of the Polis Range are volcanic and plutonic; eastward they are sedimentary. The human response to physiographic and geologic conditions has been marked.

3. The sedimentary formations are, as far as known, Tertiary.

4. There are indications of mineral deposits which might be of economic value, but which are not exploited.

5. Agriculture on a small scale and the limited and not easily accessible forests are practically the only resources of the country, and these cannot of themselves develop it much beyond its present state. The mining industry, apparently, holds out the only hope for the province.

ILLUSTRATIONS

PLATE I

Panorama from Mount Amuyao to the southwest. (Photograph by Smith.)

PLATE II

FIG. 1. Malaya Range across Abra Valley from near Cervantes. (Photograph by Martin.)
2. Abra River between Tinglayan and Lubuagan. (Photograph by Smith.)

PLATE III

FIG. 1. Rice terraces at Lubuagan; three crops are obtained each year here. (Photograph by Smith.)
2. Topography in the region of extrusive rocks; looking southeast from near Tadian. In the middle distance is an old volcanic plug. (Photograph by Smith.)

PLATE IV

FIG. 1. Limestone at Sagada. (Photograph by Smith.)
2. Nearer view of Sagada limestone, showing weathered forms. (Photograph by Martin.)

PLATE V

FIG. 1. Shale beds in trail to Lubuagan. (Photograph by Smith.)
2. Terraces at Salinas salt spring. (Photograph by Martin.)

TEXT FIGURES

FIG. 1. Outline map of northern Luzon, showing region traversed.
2. Generalized geologic section across northern Luzon, from Tagudin to the eastern coast.
3. Sketch of the vicinity of Bontoc.
4. Sketch showing slide near Sagada.
5. Profile of box cañon at kilometer 6, south of Bontoc.

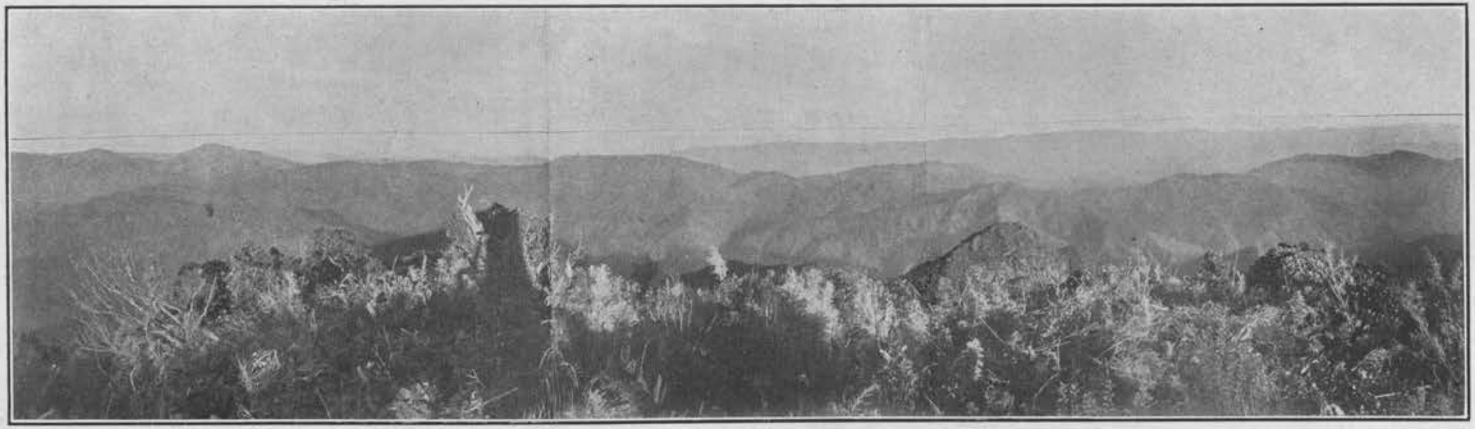

PLATE I. PANORAMA FROM MOUNT AMUYAO TO THE SOUTHWEST.

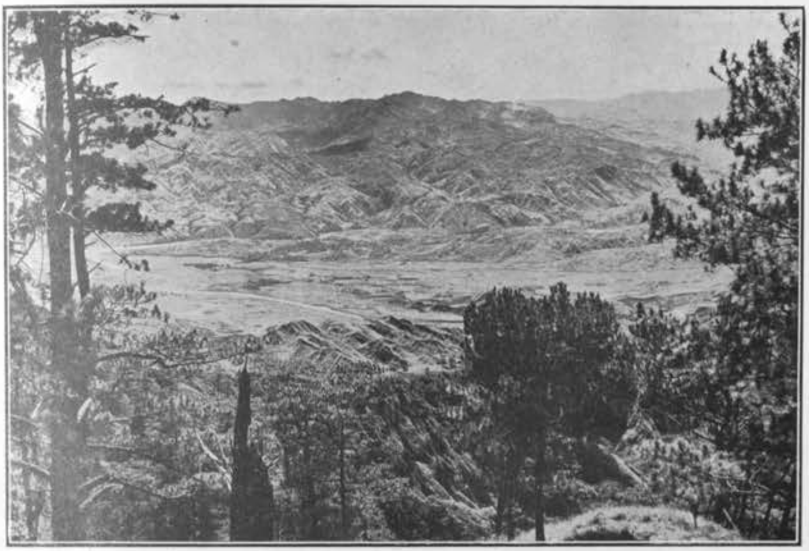

Fig. 1. Malaya Range across Abra Valley from near Cervantes.

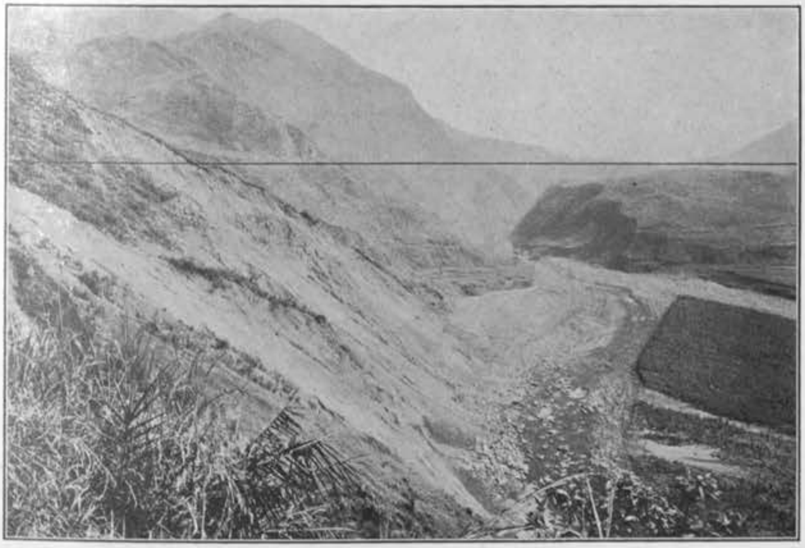

Fig. 2. Abra River between Tinglayan and Lubuagan.

PLATE II.

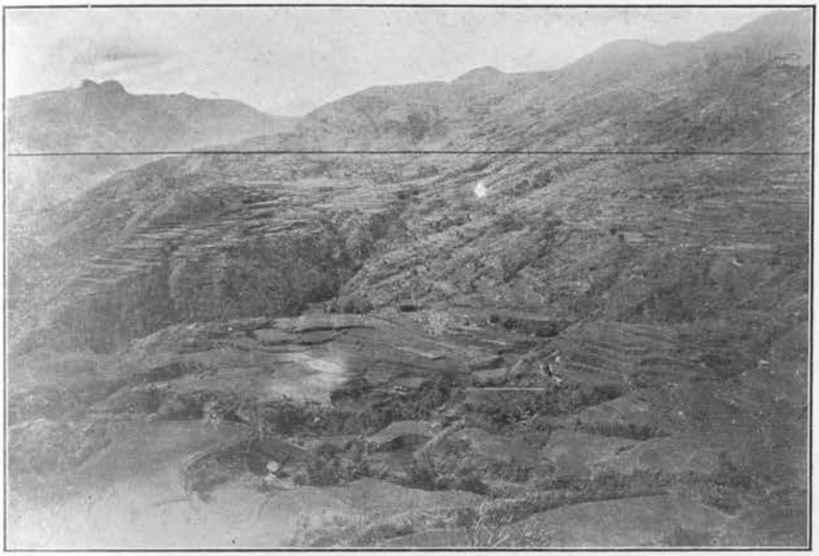

Fig. 1. Rice terraces at Lubuagan; three crops are obtained each year here.

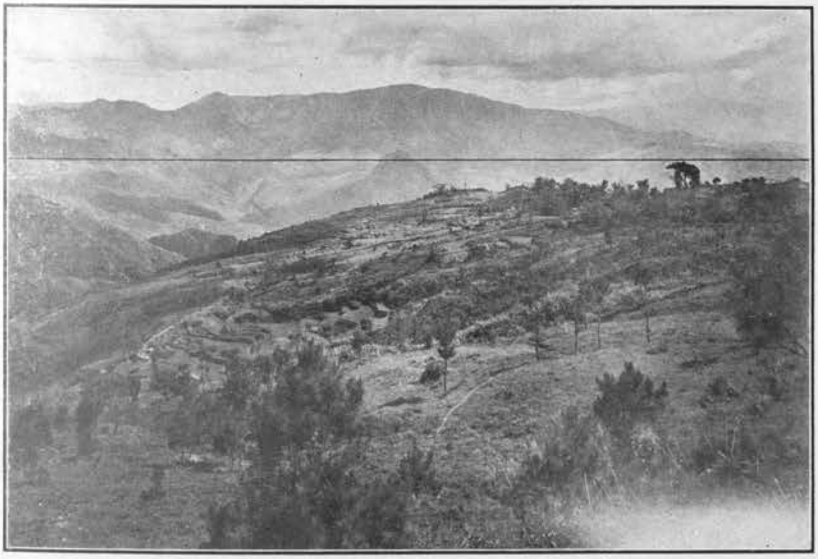

Fig. 2. Topography in the region of extrusive rocks; looking southeast from near Tadian. In the middle distance is an old volcanic plug.

PLATE III.

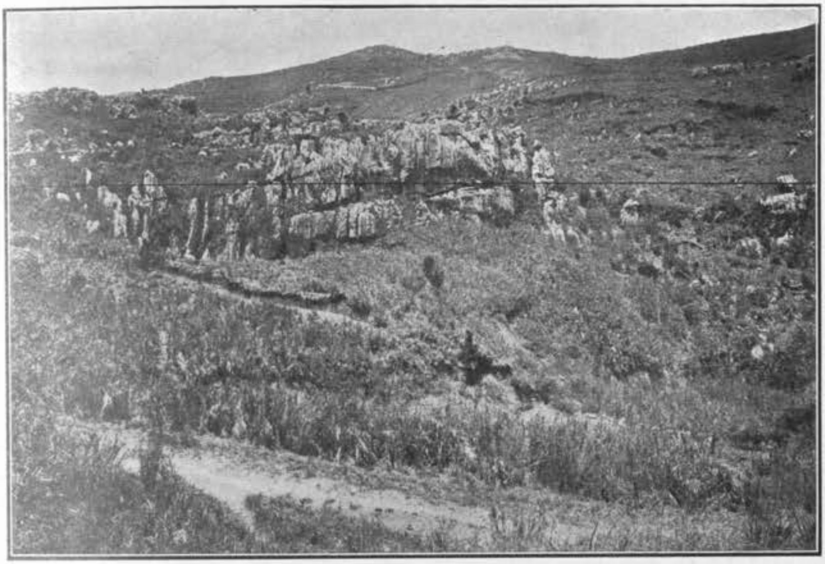

Fig. 1. Limestone at Sagada.

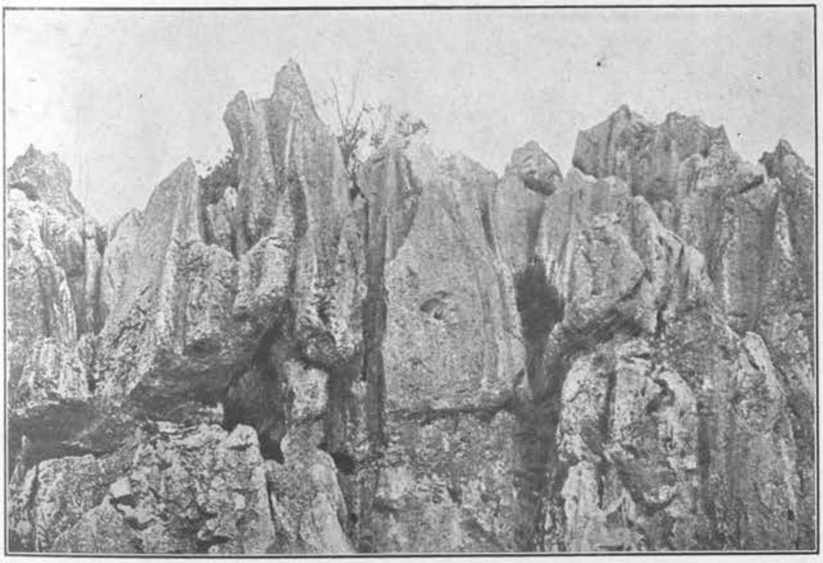

Fig. 2. Nearer view of Sagada limestone, showing weathered forms.

PLATE IV.

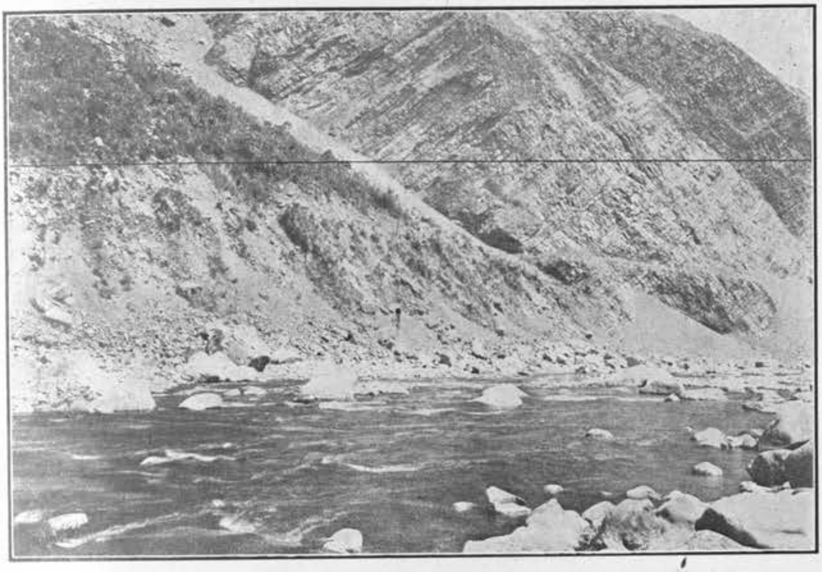

Fig. 1. Shale beds in trail to Lubuagan.

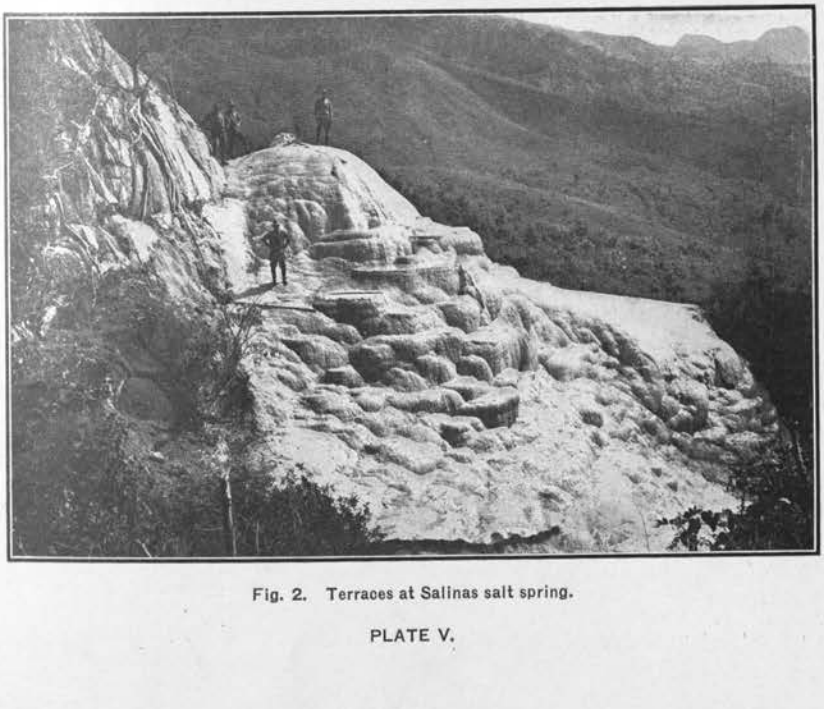

Fig. 2. Terraces at Salinas salt spring.

PLATE V.

NOTES ON THE GEOLOGY OF PANAY[1]

By WARREN D. SMITH

(From the Division of Mines, Bureau of Science, Manila, P. I.)

ONE PLATE AND 3 TEXT FIGURES

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  Ground-water resources.
GEOLOGY, SEISMIC.
SUMMARY AND CONCLUSIONS.

INTRODUCTION

Between the years 1886 and 1890 Enrique Abella y Casariego[2] carried on geologic investigations in the Island of Panay assisted by d'Almonte. The report of his work embraces detailed descriptions of the general geologic features of the country, including orography, hydrography, with the altitude of all the principal points, followed by chapters dealing with the volcanic formations and their "tufas." There are also chapters dealing with the sedimentary formations, particularly the Tertiary series, and the work closes with a part devoted to the economic geology. It is very complete as far as it goes, but omits many important points, which is to be expected when the geology of an unknown country is treated for the first time.

Mr. Maurice Goodman, formerly of the Bureau of Science, touched at a few places on Panay in the latter part of 1905, about fifteen years after Abella. The purpose of his trip was to discover workable deposits of sulphur, gypsum, limestone, building stone, and placer gold. His stay in Panay was less than ten days. He found no deposits of either sulphur or gypsum, but the time was all too short properly to pass upon the mineral resources of any district. Mr. Goodman obtained several specimens of limestone from various points in the eastern part of Panay, the

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[1] Received for publication November 27, 1914.

[2] Descripcion fisica, geol. y min. de la Isla de Panay. Chofré, Manila (1890).

analyses of which are given in his manuscript report. These show fairly pure limestone, usually with less than 1 per cent of magnesium oxide.

In the summer of 1912 Mr. Wallace E. Pratt, a geologist of the Bureau of Science, was detailed to make a rapid reconnaissance of the region about the town of Janiuay at the edge of the foothills on the eastern side of the cordillera in order to ascertain the possibilities of finding petroleum in the sedimentary formations. During his work on Suague River, which flows past the town of Janiuay, it occurred to him that there were artesian-water possibilities in that region, and he reported this to the Director of the Bureau of Science.

In the latter part of December, 1912, I was detailed to follow up the suggestions made by Mr. Pratt in regard to artesian-water possibilities, in an effort to aid the Director of Public Works in the important project of providing the city of Iloilo with an adequate supply of pure water. During the course of this work, which was confined rather closely to that section of the country immediately northwest of the city of Iloilo, the following notes regarding the general and economic geology of that part of the island were made. I was assisted in the field by Mr. Percy Kincaid, formerly of the Bureau of Science, and was furnished survey notes by Mr. R. L. Moore, of the Bureau of Lands.

GENERAL STATEMENT

A description of the general geographic features of the Island of Panay based on Abella's work[3] follows. Panay, which because of its size, richness, and population is the most important island of the Philippines after Luzon, is situated among the Visayans precisely in the center of the Archipelago and is found comprehended between the latitudes 10° 24′ 37″ and 11° 55′ 57″ north and between the longitudes 125° 30′ 16″ and 126° 50′ 24″ east of Madrid (121° 50′ and 123° 20′ east of Greenwich).

Panay has roughly a triangular shape. The greatest lengths which can be taken from north to south and from east to west, respectively, are 168 and 119 kilometers. The total area of the island is 11,580 square kilometers, of which 4,547 apply to the district of Capiz, 2,472 to that of Antique, and 4,561 to that of Iloilo. The population of Panay consists almost entirely of Visayans, and their number amounted to 775,202 according to the census of 1903. The temperature, rainfall, and vegetation conditions of Panay are very much like those of the Island of Cebu.

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[3] An unpublished translation of this important Spanish document was made by Mr. McCaskey, formerly chief of the division of mines of the Bureau of Science. This translation is on file in the library of the Bureau of Science, Manila.

One cordillera runs almost from north to south separating the Province of Antique from the Provinces of Capiz and Iloilo. This cordillera lies much nearer to the western coast than to the eastern and follows a sinuous course starting in the extreme northwest corner of the island, winding eastward, and then swinging back to the southwest corner. In the northeastern part of the island there is a mountainous cluster, but no true cordillera exists. Between these two is considerable flat country, but a little north of the center of the island is a highland tract connecting the western cordillera and the eastern mountains. Owing to the necessary vertical exaggeration in the relief map (Plate I), the true physiography of the central plain does not appear in the photograph. North and south of this divide there is low country. The largest tract of plain country is comprised of what is called the Iloilo plain, the lower part of which is chiefly a delta. The largest streams of the island start on the eastern slope of the cordillera and run east or north of this and then turn to the south and meander across the Iloilo plain. The slopes on the western side of the cordillera are much more precipitous, and the streams there are short and swift. Abella's report gives detailed descriptions of the various mountain passes, the drainage in Panay, and profiles showing the general character of the skyline in various parts of the island.

PHYSIOGRAPHY

In Abella's report there is little mention made of the physiographic and geologic factors underlying the principal characteristics of the country. The relation of topography to geology and the human response to these material factors have been shown in many parts of the world, but very little has been written on this subject in its relation to the Philippine Islands. First, I wish to draw attention to the effect of the geology upon the topography. The dominant rocks in Panay—that is, in the habitable portion—are Tertiary sedimentaries—clays, sandstones, shales, limestones, and conglomerates. We find these lying blanketlike over parts of the Iloilo plain and extending up the sides of the cordillera. In the lower part of the streams rising in the cordillera we find the course of the streams at right angles to the strike of the formation—that is, in the direction of the dip. As we go up these streams, we find tributaries coming in on both sides or joining the main stream along lines corresponding to the strike of the formation. For some distances the main streams themselves follow the strike, but as a rule they cut nearly at right angles to it. The geologic structure is reflected in the topographic aspect of the country and is characteristic of block mountains. As we look upstream from the lower courses, we see long gentle slopes; but when we ascend and look backward, we are confronted by abrupt slopes due to the upturned edges of the formation. The conditions may be represented by the diagram as seen in fig. 1.

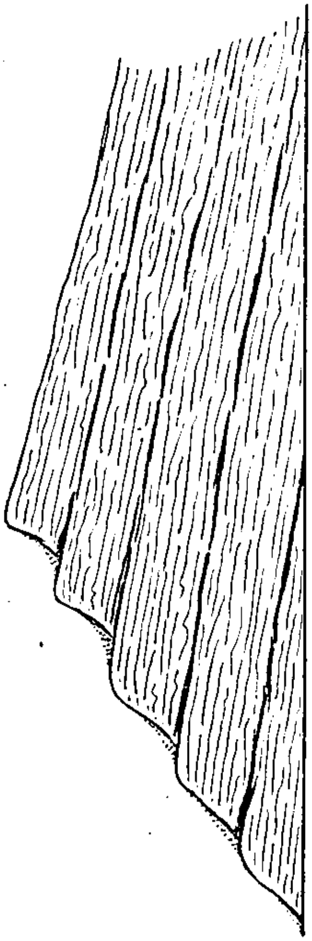

FIG. 1. Character of topography in tilted sedimentaries.

Where the rocks are hard, the streams cut through in narrow gorges, but where the formations are soft, as in the shales and some of the soft limestone, the country is open and the streams run in wide valleys. There are many places in Panay where one encounters box cañons, which at the time of high water are very difficult to pass through. These are usually in the hard resistant conglomerate. Many of these would afford excellent dam sites. Where the streams have cut back into the harder rock, such as volcanic agglomerates and diorite, there is no system to their course. They seem to follow no particular lines, save possibly here and there the jointing has exerted a local influence. When the low country is reached, the streams take their own courses again and meander irregularly over the broad plains.

DISTRIBUTION OF THE PEOPLE

In the report of the Philippine Census of 1903 there is a general map showing the distribution of the various tribes of the Islands, and the map of Panay, as shown in fig. 2, is reproduced from this. Following the cordillera and the tongue of highland, cutting across the north-central part of the island, and thence into the mountain cluster to the northeast, there is an area occupied by Bukidnons (people of the mountains). They occupy the same relative position to the people of the low country as do the mountaineers of eastern Tennessee and North Carolina to the people of the Piedmont Plateau. They comprise, for the most part, Visayans who have been pushed back into the mountains for one cause or another, their language becoming somewhat modified. At two points along the crest of the cordillera, the one in the extreme south and the other in the center of the cordillera, in the almost inaccessible region of Mount Baloy, there are two small areas said to be occupied by Negritos, the original inhabitants of the Philippines.

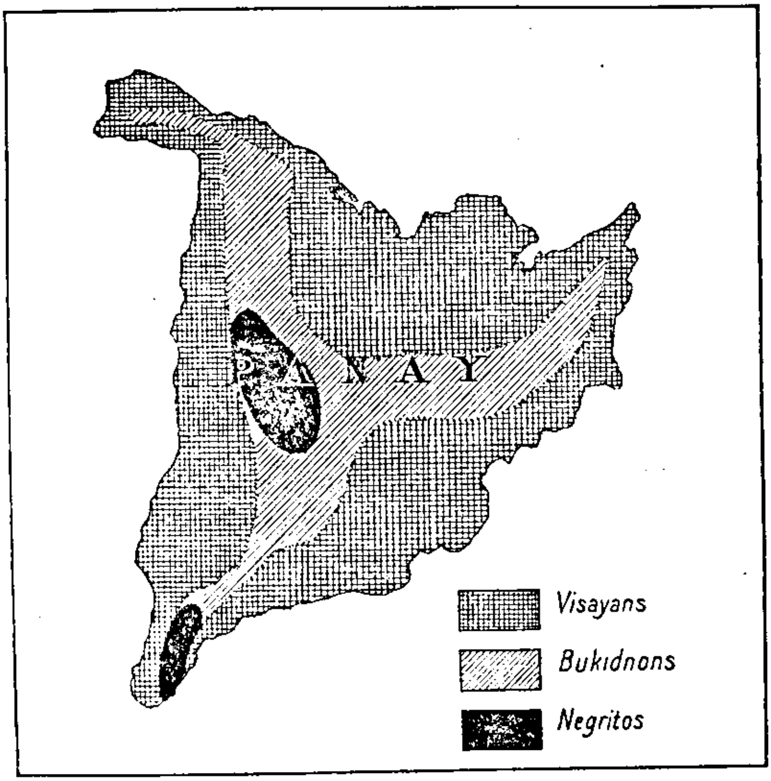

FIG. 2. Distribution of tribes in Panay.

We have here then an excellent example of the influence of topography and geology upon the distribution of the peoples. These three groups, Negritos, Bukidnons, and Visayans, are sharply defined, and their distribution is controlled strictly by geologic and topographical factors. Where the rocks are hardest and most denuded of soil, where the topography is the most rugged, where existence is the most difficult, there one finds the most primitive peoples. Now that there is a railroad running from north to south connecting the cities of the Provinces of Capiz and Iloilo, we shall see the territory of the Bukidnon people penetrated, and gradually their range will be more and more restricted.

Even among the lowland peoples of Panay there is a considerable variation in the dialects. The Filipino is, as a rule, a home-loving individual, who does not care to travel far from his friends. It is always difficult to get packers to go with one into the high mountains and into territory that is unknown to them, and all this tends to retard the dispersion of isolated groups and the free interchange of ideas and commodities.

VEGETATION

There is remarkably little forest anywhere on this island with the exception of a small area in the central portion of the cordillera. In this respect Panay resembles Cebu. The extreme deforestation is due to the *caiñgin* system, which consists in clearing and burning the forest on a small tract of land, the raising of one crop on the hilly soil, then the abandonment of this tract for a new location. The inhabitants of the high country, in Panay, at least, very rarely raise two crops in succession on the same piece of ground. The encroachment of cogon grass on the deforested area prevents the growth of a new forest and makes the land unsuitable for tillage. It is easier to clear a new spot than to prepare and open the field for crops on the old ground. This ruthless system is now having its effects on the country. Without the retaining powers of the forest and undergrowth the rainfall rapidly runs off, eroding the country and carrying enormous volumes of gravel and silt into the bottom land. This is the chief cause of the great devastation wrought by the streams in this and other parts of the Philippines. The sudden rising of these mountain streams and their pouring out onto the plain cause great floods, ruin crops, and destroy bridges, resulting in the rapid silting up of river beds and filling up of navigable streams, and the formations of bars where once existed open channels. China to-day pays a terrible annual toll in lives and money as a result of the practice of the same system in the past. There is scarcely a stick of wood left on her mountains, and the Philippines would soon be in the same plight but for the Government's timely forest conservation policy.

GENERAL GEOLOGY

As already pointed out by Abella, the general classes of rocks found on Panay are: The recent formations of the plains; the Tertiary limestone, shales, and sandstone in the foothills; the core of igneous rocks in the cordillera; and some doubtful rocks, approaching slates, which come between the igneous formations and the Tertiary series.

The best development of sedimentaries I have yet seen in the Philippines exists on Panay, and the best sections for studying them are perhaps to be found there. On Suague River Mr. Pratt estimated that the total thickness of the Tertiary series amounts to more than 9,000 meters, and if we include the older series of "slaty" rocks at the headwaters of Ulion River the total will be about 10,000 meters. I found very much the same series on Tigum River, the two streams being roughly parallel and only a few miles apart. A short distance above the barrio of Tinayoc Tigum River has cut into the hillside, affording an excellent section, which is typical, as follows:

	Meters.
Thin-bedded sandy shale	15–20
Heavy-bedded sandstone	5
Sandstone	½
Carbonaceous shale	¾
Sandstone	½
Carbonaceous shale, less than	⅓
Heavy-bedded sandstone	5
Thin-bedded sandstone and shale	16
Heavy-bedded sandstone at base	

The dip at this point is 30° to the southeast, and the strike is north 10° east. Descriptions of three different samples of the sandstone follow:

Sample 2312.—Buff to gray, very coarse, and apparently made up of triturated particles from various kinds of igneous rocks occurring in the cordillera. There is little quartz in the specimen, but fragments of ferromagnesian minerals predominate. The buff color is largely due to fragments of olivine washed out of the decomposing picrites known to occur in the cordillera. This rock has a porosity of only 5.5 per cent, the voids being filled largely with iron oxide and calcium carbonate as a cementing material.

Sample 2313.—This sample is a much finer and more even-grained grayish rock with much the same mineral composition as sample 2312. The porosity of this specimen is greater.

Sample 2314.—This sample is a still finer grained rock with more of the characters of a shale than of a sandstone.

In the same series of sediments with these sandstone beds are several layers of conglomerate, conformable and of varying thickness. These conglomerates consist of many kinds of pebbles in a firmly cemented, sandy matrix. At one place I noted pebbles and fragments of the following kinds of rocks:

1. Limestone with coral remains.
2. Andesite—3 or 4 varieties.
3. Amygdaloid.
4. Shale.
5. Rock resembling jasper, but which is probably rhyolite, as it appears to have quartz phenocrysts.
6. Diorite—coarse-grained.
7. Diorite—fine-grained.
8. Picrite—a rock rich in olivine.
9. Quartz.

Occasionally fossil shells are found, one of which is presumably *Vicarya callosa* Jenk. Hence the age of these beds is that of the Lower Miocene, or the same age as the Cebu coal measures. Fuller descriptions of these sedimentaries are given by Abella.

The shales.—The shales exposed in the lower reaches of the streams flowing from the cordillera are thin-bedded and grayish to bluish, and resemble other Tertiary shales in many parts of the Philippines, the type example of which is the Vigo series on Bondoc Peninsula, Tayabas, Luzon.[4] These shales have practically the same mineral composition as the sandstone, the chief difference being in grain size. In the upper part of Tigum River the shales are yellowish, but lower down, where we first discovered them, they are bluish. In the survey of Tigum River we found that there are at least 5,000 meters of these shales exposed from the point where the survey began to the first considerable thickness of sandstone. Of course, there are occasional thin beds of sandstone in this series, but they are negligible. Several wells have been drilled by the Bureau of Public Works in these shales in the hope of obtaining artesian water, but they have been generally unsuccessful.

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[4] Cf. Pratt, W. E., and Smith, W. D., *This Journal, Sec. A* (1913), **8**, 331.

Log of Well No. 161, Iloilo, Iloilo.

Depth in feet.	Strata.	
	Drillers' classification.	Remarks.
0- 80	Shale with numerous shale fragments and small gravel.	
80- 90	Finer shale, slightly calcareous	
90- 100	Dark shale, not calcareous	Fine quartz fragments; resembles loam.
100- 110	Adobe—heavy clay material	Result of disintegration of basic rock.
110- 130	Gray calcareous shale	
130- 150	Same as 90 to 100 feet	Finer grained.
150- 170	do	Do.
170- 190	Adobe	
190- 210	Gray shale, not calcareous	
210- 300	Shale, slightly calcareous	
300- 400	Shale, strongly calcareous	
400- 500	Fine-grained shale	Similar to previous strata.
500- 600	Shale	
600- 650	Shale, strongly calcareous	
650- 675	Sand, very fine but fairly clean	
675- 710	Adobe	
710- 800	Sand, but not so good as from 650 to 675 feet	
800- 910	Adobe	
910- 920	Shale, slightly calcareous	
920- 975	do	Much the same as from 910 to 920 feet.
975-1,100	Marl	
1,100-2,225	Fine-grained marl	

A discussion of the ground-water resources will be found on page 226. A noteworthy point in connection with the wells sunk in these shales is that the water obtained was salty. Mr. Pratt in his manuscript report has given the following satisfactory explanation of the brackishness of the water:

> If one accepts the most probable explanation of the presence of salt and other minerals in the upper clay and shale, i. e., that they came from the sea water in which the beds formed and are, consequently, original constituents of the series, it is clear that the effect of ground waters, active since the elevation of the land above sea level, would be a leaching out of the soluble salts.

I see no reason for thinking that the salt water has come from the sea. Any flow of water depends upon head, and the flow normally is from the land into the sea rather than vice versa.

Rapidly changing conditions of sedimentation must have existed throughout the formation of these beds. The thinness of certain beds, the repeated alternation in character of the

Well No. 308, Janiuay, Iloilo.

Depth in meters.	Strata.	
	Drillers' classification.	Remarks.
0- 5	Gravel and clay	
5- 10	Bowlders and clay	
10- 15	Gumbo clay	Gumbo clay is probably a stiff dark-colored clay.
15- 20	Black sticky clay	
20- 35	Joint clay	Joint clay is applied to the blue clay of the upper clay and shale series of this record.
35- 37	Blue sticky clay	
37- 41	Blue sandy clay and gravel	
41- 43	Clay and gravel	
43- 55	Blue sandy clay and joint clay	Alluvial to 43 meters. Upper clay and shale below 55 meters.
55-124	Joint clay	
124-147	Clay and loose stone	"Loose stone" is probably applied to calcareous concretions which are known to occur in the blue clay.
147-169	Joint clay	
169-175	Joint clay and loose stone	
175-187	Joint clay	
187-199	Volcanic	"Volcanic"—possibly a silt which was mistaken for volcanic tuff. The drill penetrated it 12 meters in 9 hours.
199-207	Quick clay	
207-247	Joint clay and loose stone	
247-266	Joint clay	
266-273	Joint clay and loose stone	
273-315	Joint clay	
315-320	Joint clay and loose stone	
320-348	Fine sand and gravel	
348-360	Joint clay and loose stone	
360-428	Joint clay	
428-468	Brown sand and clay	
468-490	Joint clay	
490-493	Shale	
493-506	Rock	Rock, calcareous shale.
506-527	Clay bowlders and quicksand	Clay bowlders.
527-531	Shale mixed with fine black sand	Sand from strata above mixed with shale.
531-537	Sand, gas, and salt water	

sediments, cross-bedding, and other factors all indicate that there were either repeated oscillations of level or rapidly succeeding freshets, or both. It is important to note that the conditions are unfavorable for the formation of coal deposits of economic size. The only coal seams seen by me were not over 5 centimeters thick.

STRUCTURE

The Tertiary series of shales and sandstones described above overlap the igneous core of the cordillera and constitute a great monocline dipping eastward toward the Iloilo plain. Near the

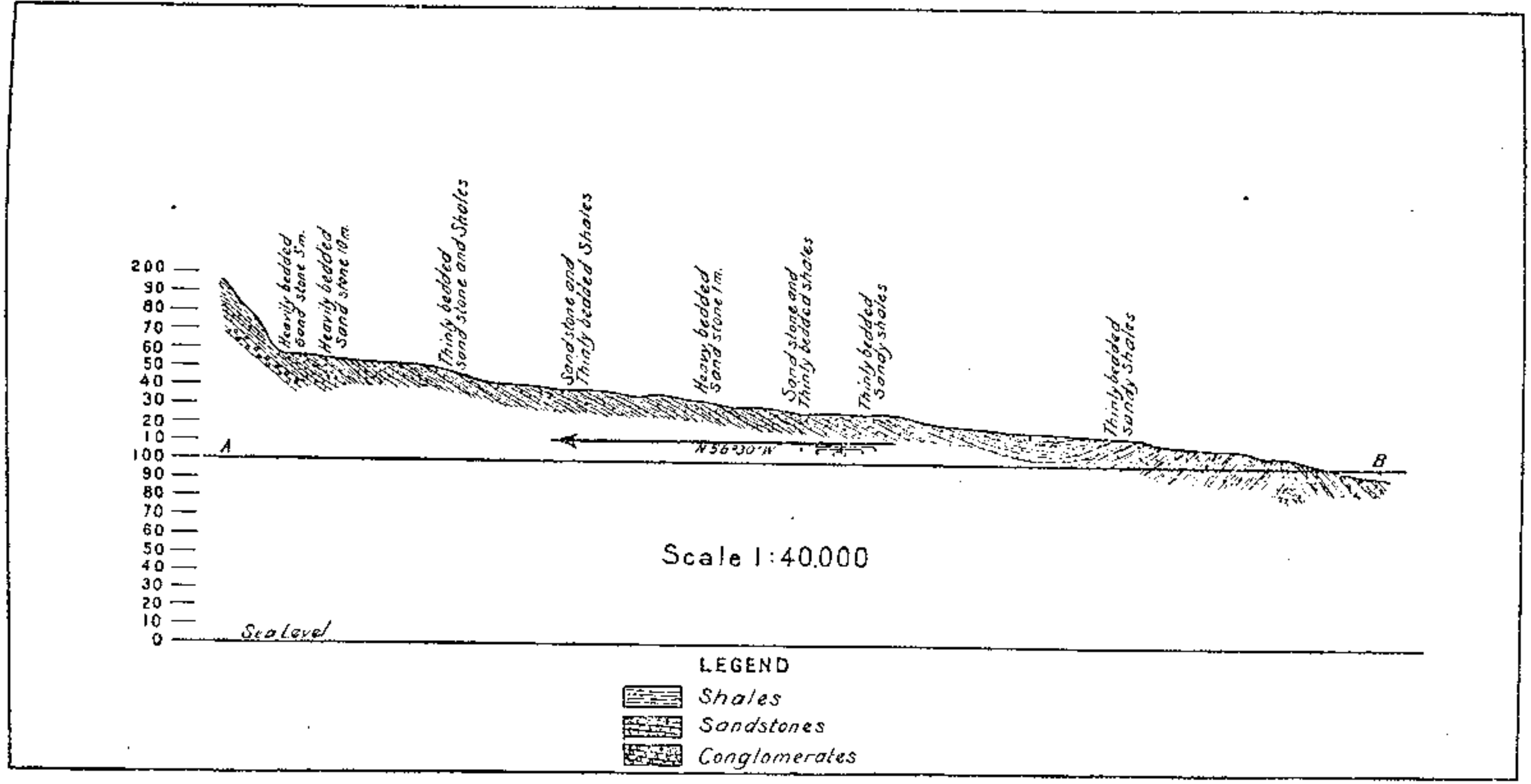
200
90
80
70
60
50
40
30
20
10
100
90
80
70
60
50
40
30
20
10
0
Sea level
A
B
Heavily bedded Sand stone 5 m.
Heavily bedded Sand stone 10 m.
Thinly bedded Sand stone and Shales
Sand stone and Thinly bedded Shales
Heavy bedded Sand stone 1 m.
Sand stone and Thinly bedded shales
Thinly bedded Sandy shales
Thinly bedded Sandy Shales
N 56°30' W
Scale 1:40,000
LEGEND
Shales
Sandstones
Conglomerates

FIG. 3. Geologic section across Iloilo Province, Panay. After Abella.

cordillera the dip of the beds is as high as 70°, but gradually this inclination decreases till the beds assume an almost horizontal position. The inclination of the beds is much greater on the Antique (west) side of the cordillera. In the foothills local undulations with reverse dips attended by some faulting are to be noted (fig. 3).

As pointed out in the discussion of the control of topography, these strata assume the attitude of tilted blocks with the abrupt slope up- and the gentler slope downstream, this slope in most cases corresponding exactly to the bedding planes. Abella's profiles are very good representations of the general conditions. A somewhat modified section, using Abella as a basis, is shown in fig. 3. The survey of Tigum River has revealed the existence of a small anticline just east of Maasin, and perhaps many others exist which would be revealed by a detailed survey of the region. These anticlines are all important in the matter of the accumulation of oil. Complete folds in the strata are, however, the exception, and the dominating structure is monoclinal. Of course, where there are anticlines the reverse type of fold, the syncline, must exist. There is one of these shown in fig. 3 just west of the Maasin anticline. As anticlines usually afford the most favorable places for the accumulation of oil, artesian waters are most favorably tapped in the synclines. The reason for this marked difference between two mobile substances is due to their difference in specific gravity. For further discussion of the petroleum possibilities in this region see page 225.

PRE-TERTIARY FORMATIONS

At an elevation of about 400 meters near the headwaters of Ulion River there is an excellent exposure of indurated sediments closely resembling slate. Intercalated with these are sills of diorite from 3 to 5 meters thick. The sills follow the bedding planes. The strike of these slaty sediments is northwest, and the dip is 30° to the northeast. No marked difference was noted between that part of the sedimentary beds nearest the sills and the interior; so it is improbable that the hard slaty character of these beds can be due entirely to the heat or pressure resulting from the intrusion of the sills.

Specimen 2322.—The rock is blue-black, very dense, exceedingly fine-grained, and has a hackly to conchoidal fracture. It shows on certain surfaces a very fine banding which is distinctly that of sedimentation. The cleavage in these beds is not typical of slates, and hence they might more properly be termed pseudoslates.

Microscopic.—The thin section of this rock is difficult to study owing to the flakes of iron oxide and numerous dark fragments which cannot be easily identified because of their amorphous condition. Fragments of quartz, feldspar, and ferromagnesian minerals are abundant. The whole aspect of the section is that of a clastic rock. Numerous fragments of globigerines and of radiolarian tests are to be seen, but neither the species nor the genera can be distinguished. This rock probably corresponds to the "clay slates" mentioned by Molengraaff [5] in his descriptions of certain rocks collected in central Borneo. He gives the following description of certain rocks encountered on Poelau Lolong River:

> The country at this point and higher upstream consists of a system of highly folded strata. The strike may be averaged at about E.-W. and E. N. E., but both strike and dip vary considerably. The strata as a rule are highly inclined and not seldom stand vertical. The oldest group in this complex is composed of clay-slate, chert, hornstone, sandstone, diabase, diabase-tuff, and diabase-tuff-breccia, also gabbro and serpentine, the latter being derived partly from a variety of olivine-norite * * * partly from picrite or from hartzburgite. * * * Some of the diabases * * * form intrusive masses, sheets, or dikes in the sedimentary formations and are therefore younger than these. * * * The cherts are sometimes full of biotite and then resemble silicified micaceous clay-slate, at other times they turn to pure jasper and hornstone. The hornstone is sometimes of a milky white colour, often marbled and alternating with bright red jasper. The chert, and particularly the jasper and pure hornstone, contain Radiolaria and are often almost entirely composed of the tests of these organisms. In the jasper, the Radiolaria can be detected with an ordinary pocket lens, and they look like so many round specks, or little grease spots the size of a pin's head. This greasy lustre is caused by the tests of the Radiolaria being filled with an aggregate of quartz which is coarser than the cryptocrystalline composition of the jasper itself. As mentioned before (page 92) these cherts with Radiolaria are of pre-Cretaceous age.

This also describes fairly accurately what we found on the headwaters of Ulion River. Just what the exact relationships are in this rather confused group of rocks has not yet been determined, but the fact that we have rocks practically identical with those of central Borneo and that they are considered to be older than the Tertiary is very important.[6]

Near the source of Ulion River I found an outcrop of jasper, the position of which was not very clear. In thin sections this proved to be similar to the rock I had described from Ilocos Norte in 1906.[7]

---

[5] Geolog. Explorations in Central Borneo. Amsterdam (1902), 174.

[6] Molengraaff, op. cit., 174.

[7] *This Journal, Sec. A* (1907), 2, 145.

Sample 2323, macroscopic.—The rock is pinkish with occasional fine black streaks in it, rather fine-grained, and fissile, so that it breaks into more or less thin slabs.

Microscopic.—The groundmass consists of cryptocrystalline silica, dotted with small roundish and oval areas filled with small irregular grains of silica but little larger than those constituting the groundmass. These roundish areas undoubtedly represent tests of Radiolaria, but nothing now remains save the cast.

In another sample tests of Radiolaria belonging to the following three genera were identified: *Stylosphæra, Dictyomitra*, and *Cenosphæra.* The species of the first-named could not be told, but under the second, the species *affinis* was distinguished without difficulty, and of the third genus, which is by far the commonest, the species *minuta* and *disseminata* were recognized.

We have now found this radiolarian chert in Ilocos Norte and Bulacan, Luzon, in Panay Island, and in Balabac Island—from the northernmost to the southernmost part of the Archipelago. Outside the Philippines the same rocks are known to occur in the Moluccas,[8] in the Federated Malay States,[9] and in California,[10] and everywhere they are referred to the Jurassic. We have every reason then to believe that this formation, or group of strata, in the Philippines is distinctly older than the Tertiary.

Associated with these red rocks are some green rocks, which in a thin section are shown to be serpentine, and these, we have seen, accompany the cherts of central Borneo.

IGNEOUS ROCKS

As Abella has devoted no little space to the igneous rocks which he found in the cordillera, I shall not discuss them at length. His list includes the following:

1. Andesite.
2. Basalt.
3. Diabase.
4. Diorite.
5. Diorite (quartz).
6. Gabbro.
7. Picrite.
8. Serpentine.
9. Tonalite.
10. Trachyte.

Of these the different varieties of andesite constitute the dominant rocks of the cordillera, and similar rocks have been described in Philippine literature. Of the rest we need call attention only to the tonalite and the picrite. We have found these quartz-mica-hornblende-diorites in various parts of the Philippines, but they are not common.

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[8] Martin, R., Reisen in den Molukken. Geolog. Theil. 2te Lief., 171.

[9] Scrivenor, J. B., Geol. Mag. (1912), **9**, 241–48.

[10] Fairbanks, H. W., *Journ. Geol.* (1895), **3**, 418.

As the picrites are still more uncommon, I shall give Abella's own description of them:

> The *picrites* have a beautiful emerald green color with bronze metallic reflections of a crystalline texture, and in them is seen olivine, augite, and bronze hypersthene, a white mass being distinguished among these crystals, semigranular, almost pulverulent, which at some time might have originated from a preëxisting feldspar or nepheline, which cannot now be classified as such, nor give, therefore, character to the rock. Under the microscope this white mass resolves itself into a whitish magma, amorphous and decomposed, which in the polarized light emits, notwithstanding, certain pale gray bluish and yellowish colorizations, all of which confirms the supposition attributing to it the feldspathic and nephelinic origin, * * *.
>
> Based on these characters and on the almost holocrystalline texture which the three elements of this rock display, we shall classify it as peridotic, and designate it as picrite.

The western cordillera certainly affords an interesting field for the petrographer, and its thorough exploration may some day reveal deposits of great commercial value. For instance, the "picrites" which Abella mentions are about the most basic rocks known, and in their vicinity it is reasonable to expect that valuable deposits of metals will be found.

ECONOMIC GEOLOGY

In the third part of his report Abella discusses the occurrences of various nonmetals and metals. Since Abella's time a slight amount of prospecting has been carried on in Antique Province by Americans, with the result that promising deposits of chromic iron and copper have been reported, but nothing of value has been found on the eastern side of the cordillera. The presence of petroleum and coal has also been reported. Specimens of wolframite have been sent to the Bureau of Science by two persons from Antique Province, who, however, gave no definite information with regard to them. If there is any considerable quantity, it will be valuable. Serpentine containing asbestiform minerals has also been noted in the same province.

The presence of petroleum at Janiuay, Iloilo Province, was reported many years ago, but during a recent reconnaissance of the province, I failed to see any oil. However, at Janiuay I visited a well 537 meters in depth, which was bored nearly two years before by the Bureau of Public Works for artesian water, and which was emitting gas and salt water intermittently. This may be an indication of the presence of petroleum at a lower horizon. That this is not simply marsh gas is, I believe, shown by the analysis.

Analysis of the gas collected by Wallace E. Pratt[a] *from the Janiuay well in 1912.*[b]

	Per cent.
Hydrogen	5.2
Methane	89.4
Ethane	0.0
Carbon dioxide	0.6
Nitrogen	4.3
Oxygen	0.0
Carbon monoxide	0.5

[a] *Mineral Resources P. I. for 1912* (1913), 47.

[b] Analysis by Forrest B. Beyer, chemist, Bureau of Science.

It is known, of course, that methane is the chief constituent of natural gas and that ethane is usually found in it, but examples are known where the latter is absent. The presence of hydrogen and of nitrogen particularly seems to argue in favor of the supposition that this gas is not merely a product of vegetable decay. It is not impossible, of course, to have a marsh deposit at almost any depth in sedimentary formations. The facts, however, that we have some considerable depth, presence of salt water, and these extra constituents seem to make it highly probable that this is natural gas and is associated with a deposit of petroleum. As to the amount of oil likely to be present in these formations we can only conjecture.

As traverses were made along the streams in this part of the island, close watch was kept for any oil seeps, but nothing was seen even suggestive of the presence of oil. It is possible, of course, that the oil is of so light a grade that on evaporation it leaves no residue easily detected on the rocks and thus would easily be overlooked.

The sedimentary formations are so folded that what oil may be present would be collected into natural reservoirs. There are indications also that sandy beds exist which would afford sufficient pore space for the retention of any oil that may be present. For these reasons we can say that it is not at all unlikely that petroleum does exist in this island.

GROUND-WATER RESOURCES

The importance of an adequate supply of pure water in tropical countries no longer needs any argument. The need for a supply of uncontaminated water for the growing city of Iloilo has become pressing. Several unsuccessful deep wells have been bored at Iloilo and in the neighboring towns. One well at Iloilo penetrated to a depth of about 800 meters in clays, sands, and shales and struck no potable water. The well at Janiuay already mentioned did not get through the thin-bedded shales and resulted only in striking salt water and gas. A number of comparatively shallow wells near Iloilo which did not go below the alluvium obtained water which in some cases proved to be brackish and in others to have a taste of iron. After these unsuccessful attempts were made, a scheme for diverting water from Tigum River into a reservoir from which it was to be piped a long distance to Iloilo was projected. This, however, would entail the expenditure of at least a million pesos, and naturally there was some hesitation about undertaking it. Finally I was detailed to visit the region with instructions to look into the artesian-well possibilities. After three weeks on the ground I submitted a report giving the following conclusions:

1. The artesian conditions of the sandstones and conglomerates are not sufficiently favorable for us to recommend any further expenditure of money in this direction.
2. It is deemed probable that an adequate water supply can be obtained from the deep gravels in the alluvial deposits in the lower end of the Iloilo plain.
3. More detailed study of this region should be made along the lines adopted by the hydrographic branch of the United States Geological Survey.
4. Geologic investigation should precede all artesian-well projects.

The first conclusion was arrived at after due consideration of the depth, inclination, thickness, and porosity of the possible water-bearing strata, all of which appeared as pointing to very unfavorable conditions, and in view of the past experience in this district in well-boring, other and simpler means of getting water should be tried first.

Since this investigation was made, reports from that locality state that in some of the wells near Iloilo, particularly the one at Molo, the water has improved and is losing some of its brackish taste. In one of these wells I noted a slight taste of iron, which would not be harmful and even might be beneficial. It is my expectation that the water from these wells will in time become entirely potable, and that sufficient water for the supply of the city of Iloilo will be obtained from numerous comparatively shallow (75 to 300 meters) wells in the ancient gravels of this plain.

SEISMIC GEOLOGY

The seismic disturbances in this island have been discussed already.[11] It seems reasonably certain that the majority of the disturbances which have occurred there are local and are of the rockfall type. I have seen some landslips which have resulted from the slipping of the sediments, particularly the shales, over one another along bedding planes. If these are large enough, they can easily set up vibrations which would be recorded by seismographs.

Other disturbances have been of greater intensity and were due to displacements along the line of contact between the sediments on the western side of Guimaras Island and the igneous formation on the east.

It is possible, also, that other differential movements have taken place between the valley alluvium and the mountain mass, which would give rise to seismic disturbances.

There is no evidence as far as I know of vulcanism on the island since the Pleistocene, at least, to which we could attribute any of these disturbances. Whatever their origin, they have been of minor importance, and Panay is now one of the most stable parts of the Archipelago.

SUMMARY AND CONCLUSIONS

The relation of geology to the topography and indirectly the bearing it has upon the distribution and activities of the people has been shown.

The vegetation of the country shows the devastating effects of the caiñgin system, and the effect of this upon the economic welfare of the people has been indicated.

The existence of a hitherto suspected but unverified new-old formation, almost certainly Jurassic in age, has been proved.

Attention has been called to new prospects in mining and the favorable geologic features connected therewith. Deeper drilling for oil in the vicinity of Janiuay is recommended.

The ground-water resources of a portion of the island have been touched upon, and the possibility of utilizing the water contained in the ancient buried gravels of the Iloilo plain has been pointed out.

Attention has been called to the seismic geology. Panay is one of the most stable parts of the Archipelago, and the majority of the few earthquakes occurring on the island are due to rockfall and hence are local.

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[11] Saderra Maso, Miguel, and Smith, W. D., *This Journal, Sec. A* (1913), **8**, 199.

ILLUSTRATIONS

PLATE I. Photograph of a relief map of Panay.

TEXT FIGURES

FIG. 1. Character of topography in tilted sedimentaries.
2. Distribution of tribes in Panay.
3. Geologic section across Iloilo Province, Panay. After Abella.

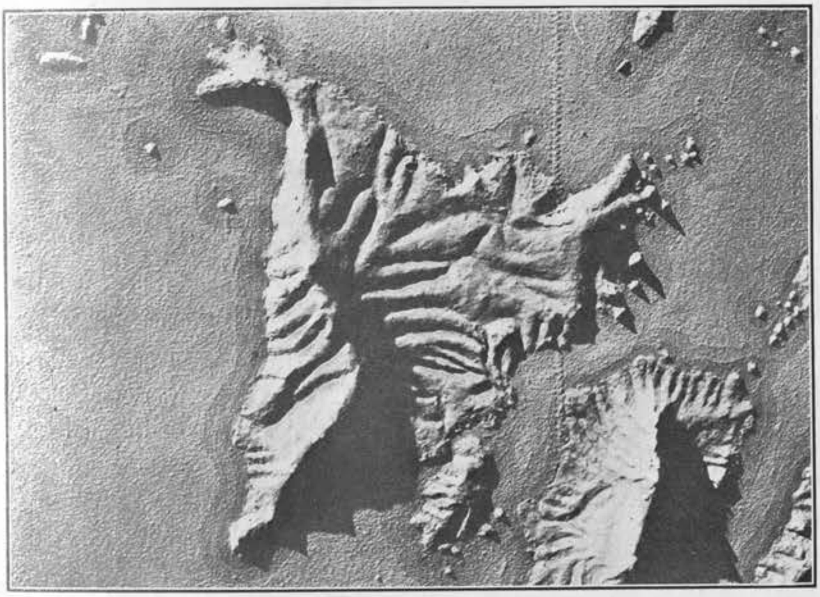

PLATE I. PHOTOGRAPH OF A RELIEF MAP OF PANAY.

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MEDICINE

REPORT OF THE INTERNATIONAL PLAGUE CONFERENCE

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